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INSIDE

What makes the brightest minds shine

How to stay sharp into old age

Exercises that boost brainpower

Prime yourself for creative leaps

Can a simple pill turbocharge your mind?

PLUS

Ways to draw out your child's brilliance

Tap Your Hidden Smarts

# Your Inner Genius

WINTER 2019

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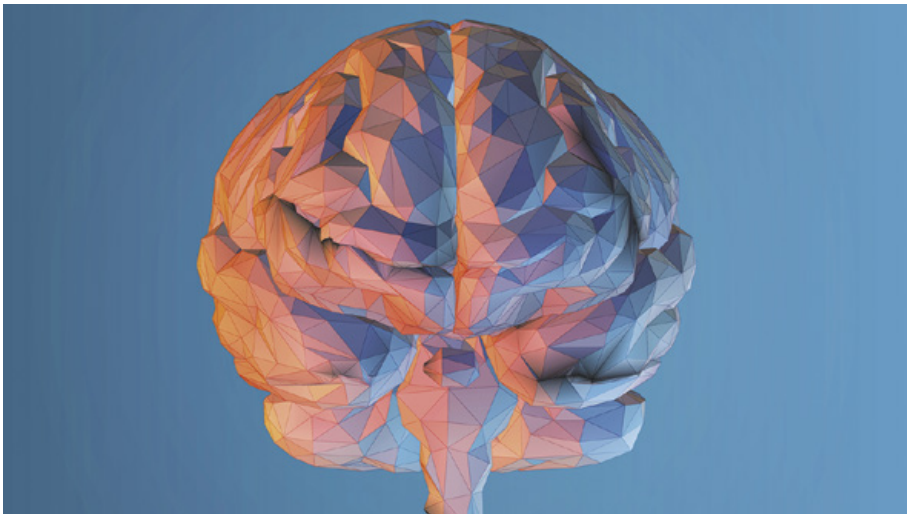

FROM THE EDITOR

# Mind Gains

PLENTY OF RESEARCH HAS SHOWN THAT THE MOST INTELLIGENT AMONG US HOLD MORE positions of power, make more money, attain higher-level jobs and seem to have better luck overall. No wonder so many people search for ways to boost their intelligence and creativity. More important perhaps, dozens of studies have found that a higher IQ (intelligence quotient) is directly related to longevity. One landmark study from the 1930s found that a 15-point IQ advantage conferred a 21 percent better chance of survival into old age. It not only pays to be smart, your life can depend on it.

Although we're all eager to learn how to improve our brainpower—and there *are* some realistic solutions—scientists are still grappling with the very nature of intelligence. As Dean Keith Simonton writes on page 4, IQ is not the only, nor necessarily the best, measure of genius. Creative output may be a better determinant. Or perhaps, as some have discovered, it's your critical thinking abilities, not just raw talent, that make you seem brighter than the rest (*page 20*).

Some intriguing mind-boosting tools are under development. Early investigations into transcranial direct-current stimulation, or the use of mild electric current to strengthen synaptic connections, seem promising (*page 32*). And several recent studies have found that the drug modafinil, developed to treat sleep disorders, may enhance cognition (*page 28*). But two tactics to increase your brainpower seem surefire. The first is exercise—substantial research has shown that movement keeps you sharp well into old age (*page 42*). The second is your attitude. As Carol S. Dweck writes on page 36, a growth-oriented mindset—that is, believing you have the capacity to improve—sets you up for a lifetime of actually getting smarter.

Nowhere is fostering mental acuity more vital than with children. Many researchers make a strong case for nurturing gifted kids from a young age and allowing them to follow their passions (*page 64*). New devices and methods are emerging to determine intelligence at ever younger ages (*page 78*) and to train children up in math and verbal skills so they can excel later in life (*page 82*).

It may not seem evident when you check the daily news, but the average human IQ has been increasing steadily over the past century (*page 96*). If we are smart, we will continue the trend and work to create a world where all individuals have the opportunity to shine as brightly as they can.

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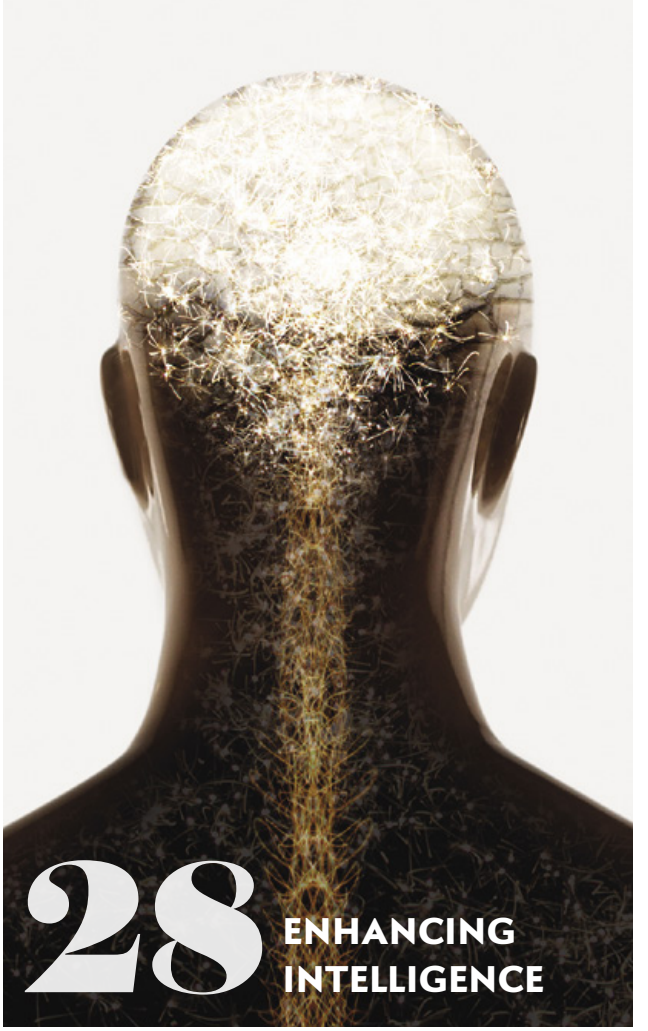

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YOUR INNER GENIUS
**Origins of Brilliance**

# The Science of GENIUS

Outstanding creativity in all domains may stem from shared attributes and a common process of discovery

*By Dean Keith Simonton*

*Illustration by Noma Bar*



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**PSYCHOLOGISTS** often assess geniuses by their achievements, such as painting the Sistine Chapel, rather than by IQ scores.

IDENTIFYING GENIUS IS A DICEY VENTURE. CONSIDER, for example, this ranking of "The Top 10 Geniuses" I once stumbled across on Listverse.com. From first to last place, here are the honorees: Johann Wolfgang von Goethe, Leonardo da Vinci, Emanuel Swedenborg, Gottfried Wilhelm Leibniz, John Stuart Mill, Blaise Pascal, Ludwig Wittgenstein, Bobby Fischer, Galileo Galilei and Madame de Staël. What about Albert Einstein instead of Swedenborg? Some of the more recently deceased might also deserve this appellation—Stephen Hawking comes to mind. Another female genius or two might make the cut, perhaps Marie Curie or Toni Morrison. And if a chess champion, Fischer, is deemed worthy, other geniuses outside the arts and sciences ought to deserve consideration—Napoleon Bonaparte as a military genius, Nelson Mandela as a political genius or Bill Gates as an entrepreneurial genius, to name a few candidates. All these questions and their potential answers can make for some lively cocktail party conversations. What they reveal is how little we understand about the origins of intellectual and creative eminence. Explorations of this age-old debate have long sought to tease out the common features of geniuses working in disparate domains. The existence of unifying threads—including genetic factors, unusually broad interests and a link with psychopathy—suggests that the mind of a genius has a discernible shape and disposition.

Ultimately the goal is to explain how an eminent thinker arrives at his or her world-changing moment, or moments, of insight. Although such breakthroughs often seem to appear in a flash, the underlying mechanisms are likely to be much more orderly. According to one theory I helped to develop, a genius hunts widely—almost blindly—for a solution to a problem, exploring dead ends and backtracking repeatedly before arriving at the ideal answer. This line of research is helping us to investigate whether genius can be cultivated, unleashing a wealth of new ideas for the benefit of all.

## THE MEANING OF GENIUS

THE FIRST HURDLE in the study of genius is to settle on a working definition. The word itself harks back to ancient Roman mythology, according to which every male was born with a unique genius that served as a kind of guardian angel, and every female had a juno. Much later, after the Renaissance, the word became more exclusive in its application, with only a few people showing genius. Philosopher Immanuel Kant believed, for example, that a genius was someone who produced works that were both original and exemplary. The term did not acquire scientific meaning until the late 19th century, when psychologists came to define genius in two distinct ways.

### IN BRIEF

**Genius has been viewed** two different ways: as achieved eminence and as exceptional intelligence. The former metric offers the more useful definition.

**Genetics and life** experiences both contribute to genius. Creative contributions can occur only after a domain has been mastered, but genetics can help a person improve faster and accomplish more with a given amount of expertise.

**Genius can share** certain potentially negative traits with mental illness, but when these traits are combined with specific positive attributes, the result is creativity rather than psychopathology.

**A scientific genius** has different expertise than an artistic genius, but all creative geniuses may depend on the same general process: blind variation and selective retention.

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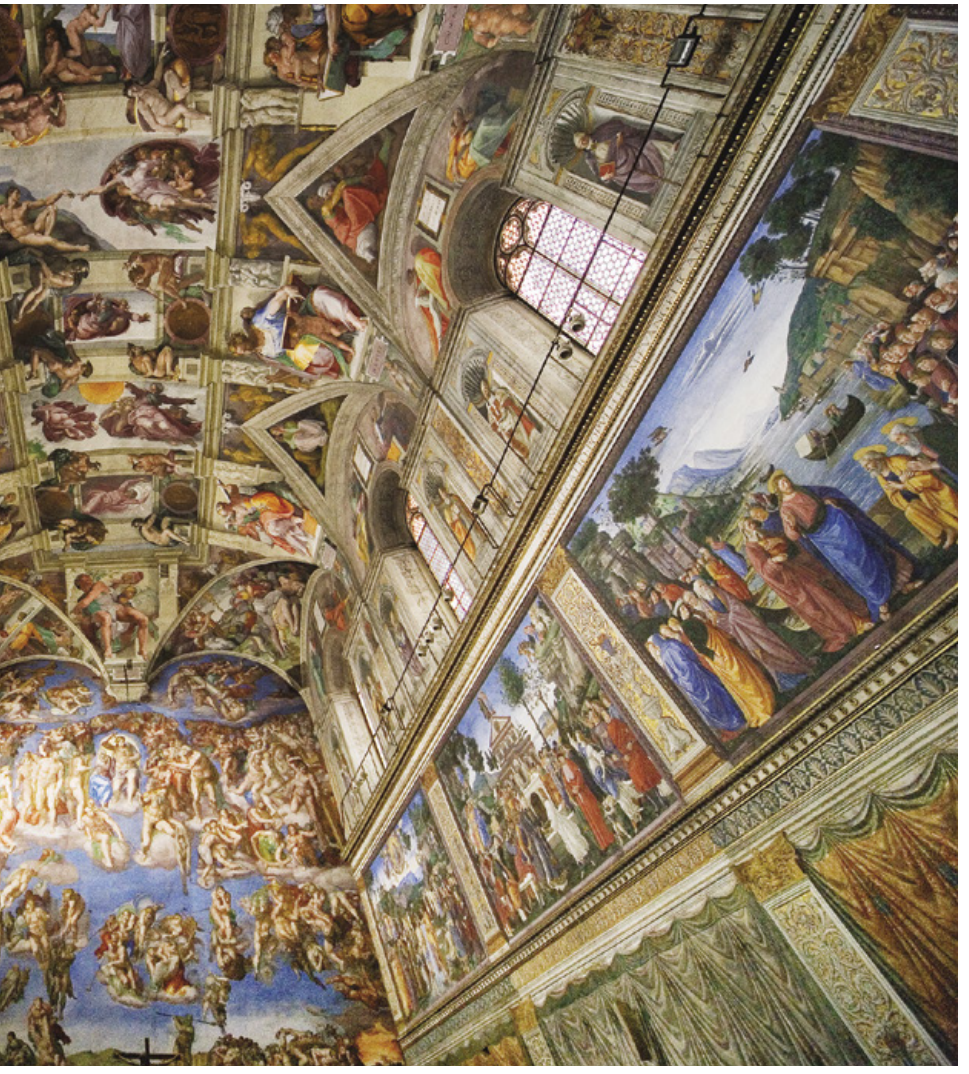

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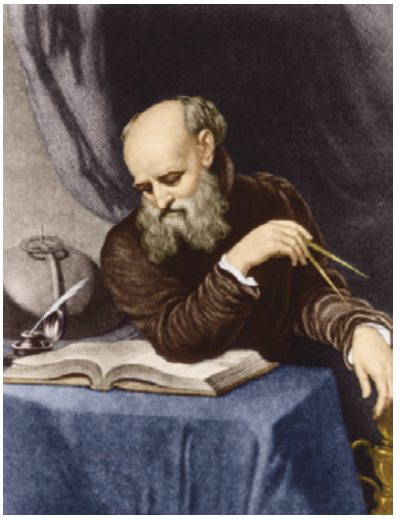

**TO BUILD** the two-lens telescope he used to survey the skies, Galileo had to first learn how to grind his own lenses and discover the optimal lens combination.

The first approach was to identify genius with exceptional achievement, as Kant did. These accomplishments elicit admiration and emulation from other experts in that field and often the world at large. Unquestioned examples of such works include Newton's *Principia,* Shakespeare's *Hamlet,* Tolstoy's *War and Peace,* Michelangelo's Sistine Chapel frescoes and Beethoven's Fifth Symphony. Even though this definition can be extended to encompass extraordinary leadership, such as military brilliance, and prodigious performance, including some chess grandmasters, most scientific research concentrates on outstanding creativity within the sciences or the arts, which will also be the focus here.

The second definition of genius coincided with the emergence of intelligence tests in the first half of the 20th century. A genius was someone who scored sufficiently high on a standard IQ test—usually landing in the top 1 percent, with a score above 140, as proposed by psychologist Lewis Terman, the formulator of one of the original intelligence tests. These two definitions have little in common. Many persons with superlative IQs do not produce original and exemplary accomplishments. One example is Marilyn vos Savant, who was once certified by the *Guinness Book of World Records* as having the highest recorded IQ of any living person. Her weekly Ask Marilyn column for a Sunday newspaper supplement did not inspire a new genre of science, art or even journalism. And many exceptional achievers do not attain genius-level IQs. William Shockley, for example, received a Nobel Prize in Physics for coinventing the transistor yet had an IQ score well below 140. Exceptional achievement, then, seems the more useful measure.

Too often in popular writing, genius is conceived as a discrete category—this person is a genius, but that person is not. Yet just as people can vary in IQ, they can also differ in the magnitude of their creative achievements, with either a single notable contribution or a lifetime of prolific work. One such "one-hit wonder" is Gregor Mendel, who attained lasting fame for a single paper that reported his classic experiments in genetics. Had Mendel never taken an interest in breeding peas, his name would be unknown today. Charles Darwin's fame, in contrast, rests on far more than *On the Origin of Species.* Nobel laureate Max Born once said that Einstein "would be one of the greatest theoretical physicists of all time even if he had not written a single line on relativity." Hence, Darwin and Einstein exhibited greater genius than did Mendel. Accordingly, much research is devoted to assessing relative degrees of genius—most often gauged by creative productivity.

## ORIGINS OF GENIUS

FINDING THE SOURCES of consummate creativity has occupied the minds of philosophers and scientists for centuries. In 1693 English poet John Dryden wrote, "Genius must be born, and never can be taught." Two and a half centuries later French author Simone de Beauvoir countered, "One is not born a genius,



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## Measuring Genius

**In 1926 Catharine Cox** estimated the IQs of 301 eminent individuals. Using biographical data on early intellectual development, she and her collaborators calculated IQ using the formula IQ = 100 × MA/CA, where MA = mental age and CA = chronological age. Some representative results are shown here. (The actual scores are taken from a secondary analysis of her data that I published with Anna V. Song of the University of California, Merced.) These rankings illustrate the value of using achieved eminence, rather than intelligence test scores, as a measure of genius. Philosopher George Berkeley, for example, did not leave a greater mark on the world than Newton or Leonardo. Further, eight of these creative geniuses have IQs below the "genius threshold" of 140. *—D.K.S.*

| IQS | SCIENTISTS | PHILOSOPHERS | WRITERS | ARTISTS | COMPOSERS |
|---|---|---|---|---|---|
| 190S | | Gottfried Wilhelm Leibniz | Johann Wolfgang von Goethe | | |
| 180S | Blaise Pascal | John Stuart Mill | Voltaire | | |
| 170S | Pierre-Simon Laplace | George Berkeley | Samuel Taylor Coleridge | | |
| 160S | Isaac Newton | René Descartes | Charles Dickens | Michelangelo | |
| 150S | Johannes Kepler | Baruch Spinoza | Michel de Montaigne | Leonardo da Vinci | Wolfgang Amadeus Mozart |
| 140S | Charles Darwin | Emanuel Swedenborg | Molière | Peter Paul Rubens | Ludwig van Beethoven |
| 130S | Nicolaus Copernicus | Jean-Jacques Rousseau | Robert Burns | Rembrandt van Rijn | Gioachino Rossini |
| 120S | | | Miguel de Cervantes | Bartolomé Esteban Murillo | Cristoph Willibald Gluck |

one becomes a genius." The first scientific investigation devoted exclusively to genius concerned this precise issue. In 1869 Francis Galton published *Hereditary Genius,* in which he argued that genius is innate, based on his observations that geniuses tend to emerge from lineages that included other brilliant individuals. In response to criticisms, Galton later introduced the well-known nature-nurture issue. He conducted a survey of famous English scientists to discover some of the environmental variables involved in nurturing brilliance, and he examined factors such as birth order and education.

By the second half of the 20th century psychologists had moved to an extreme nurture position, in which creative genius rested solely on the acquisition of domain expertise. This idea was frequently expressed as the "10-year rule." Nobody can expect to reach the heights of creativity without mastering the necessary knowledge and skill because only experts can create—or so the thinking went. Indeed, Einstein learned lots of physics before he commenced his creative career.

This explanation cannot account for all the details, however. First, geniuses often spend less time acquiring domain expertise than their less creative colleagues. Studies have linked accelerated acquisition with long, prolific and high-impact careers. The 10-year rule is an average with tremendous variation around the mean. Further, major breakthroughs often occur in areas where the genius must create the necessary expertise from scratch. Telescopic astronomy did not exist until Galileo pointed his new instrument toward the night sky to discover what had never been seen before nor even expected. The moon had mountains, Jupiter had moons and the sun had spots!

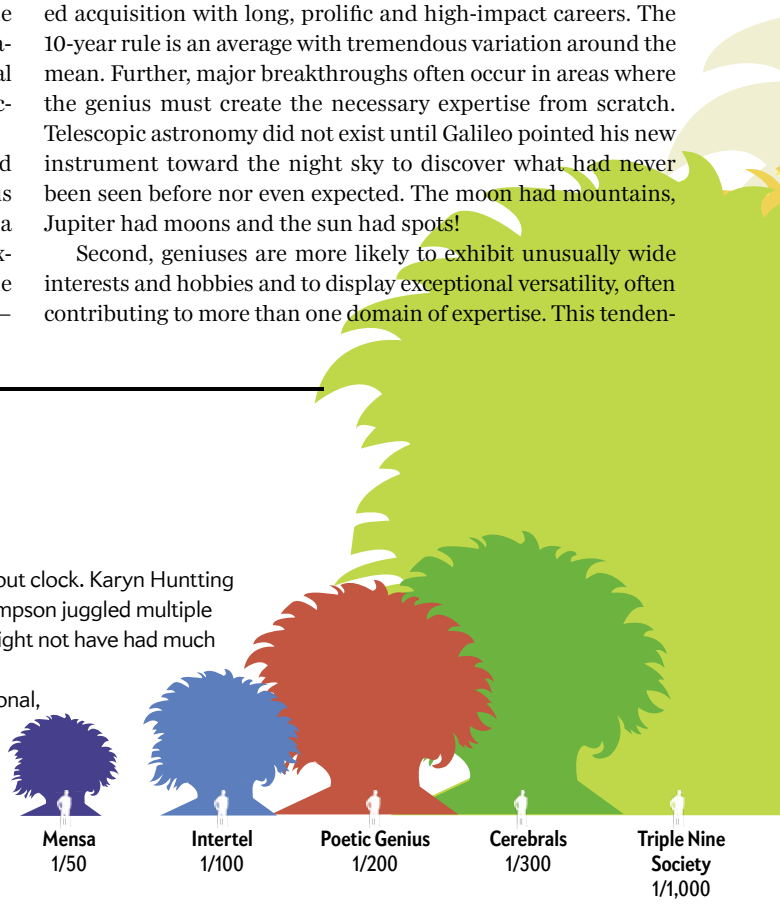
Second, geniuses are more likely to exhibit unusually wide interests and hobbies and to display exceptional versatility, often contributing to more than one domain of expertise. This tenden-

## When High IQs Hang Out

### "Genius" societies offer a social network for the top tier of test takers *By Lena Groeger*

**Kevin Langdon was writing** several books and designing an inside-out clock. Karyn Huntting Peters was organizing a global problem-solving network. Alfred Simpson juggled multiple Web-programming projects in his free time. These three people might not have had much in common—except for their unusually high IQs.

All three belong to exclusive high-IQ societies. Mensa International, whose members' test scores must land above the 98th percentile (or one in 50), may be the most popular, but it is just one option for the discerning test taker. The Triple Nine Society demands an IQ in the 99.9th percentile, whereas the Mega Society cuts off at the 99.9999th percentile (one in one million). The memberless Grail Society claims to accept one in 100 billion people—no one has applied so far.



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cy not only was true in the era of Renaissance men but also is evident today. According to a 2008 study, Nobel laureates in science are more involved in the arts than less eminent scientists. Given that geniuses might not sleep any less than the rest of us, these extraneous activities would seem to distract from a dogged focus on a narrow field of interest. Einstein slept even more hours than the norm, but he still took time off to play Bach, Mozart and Schubert on his violin. At times these avocational activities inspire major insights. Galileo was probably able to identify the lunar mountains because of his training in the visual arts, particularly in the use of chiaroscuro to depict light and shadow.

The expertise acquisition theory also undervalues the genetic components that underlie a large number of cognitive abilities and personality traits that correlate with genius. In a 2008 meta-analysis, I found that at least 20 percent of the variation in creativity could be attributed to nature. For example, creative achievement is strongly associated with the personality trait of openness to experience, a highly heritable characteristic. The broad interests in art and music of many geniuses are clear manifestations of this trait. Many other predictors of achievement also have high heritabilities, such as cognitive and behavioral flexibility, along with a tolerance of ambiguity and change.

Nurture may still account for the lion's share of genius, and mastering a domain remains central. At the same time, genetics contributes heavily to the rate at which someone acquires the necessary skills and knowledge. Those with more innate talent can improve faster, launch their careers earlier and be more productive. In addition, genetics may help explain the different trajectories of equally well-trained individuals. Einstein did not know as much physics as many of his contemporary theoretical physicists, but what he did know went a long way. He could honestly say, "Imagination is more important than knowledge."

These influences are just a few of the ways genetics shapes the potential for genius. Let it suffice to note that I have probably understated the impact of genes on genius.

## MADNESS AND MAGNIFICENCE

RESEARCHERS HAVE LONG BEEN TANTALIZED by the question of whether the biological endowment of a genius also confers great setbacks. Greek philosopher Aristotle is reputed to have said, "Those who have become eminent in philosophy, politics, poetry and the arts have all had tendencies toward melancholia."

This idea received wide currency in the 19th and 20th centuries at the hands of psychiatrists and psychoanalysts. Among the great writers, Virginia Woolf, Anne Sexton and Sylvia Plath all committed suicide. Vincent van Gogh did as well, and earlier he had cut off part of his ear to give to a prostitute. Newton sometimes suffered from extreme paranoia, and Galileo, possibly an alcoholic, was often bedridden with depression. Nevertheless, many psychologists have argued that such cases are the exceptions, not the rule. Some positive psychologists today consider creative genius a human strength or virtue.

My 2005 review of the literature, which summarized studies with varied methodologies, indicates that the association between genius and mental illness has considerable strength. Very creative writers tend to obtain higher scores on the psychopathology-related parts of the Minnesota Multiphasic Personality Inventory, a widely accepted personality test. A study using another instrument, the Eysenck Personality Questionnaire, found that extremely creative artists—and high-impact psychologists, for that matter—tend to receive elevated scores on the test's psychoticism scale, meaning that they are, among other things, egocentric, cold, impulsive, aggressive and tough-minded. Last, highly eminent scientists tend to score higher on sections of the Cattell 16 Personality Factor Questionnaire that signify they are withdrawn, solemn, internally preoccupied, precise and critical. All told, top performers are not a very normal bunch.

Psychiatric studies bolster these results. The rate and intensity of certain psychopathic symptoms, such as depression and alcoholism, are noticeably higher in very creative individuals than in the general population. Research also suggests that these divergent thinkers are more likely to come from family lines that are at higher risk for psychopathology. Even if an extraordinary innovator is "normal," his or her family members may not be.

In line with these findings, in 2009 psychiatrist Szabolcs Kéri, then at Semmelweis University in Hungary, found a genetic basis for both creativity and psychosis in a variant of the

---

Although members of IQ societies do not fit a single profile, they often join in search of a sense of belonging. "I've heard a lot of people refer to themselves as aliens until they found a group like this," says Peters, who serves as an officer of the Prometheus Society. "But get them all together, and they become extremely talkative—they're up until five in the morning." Langdon, who has founded or co-founded several high-IQ societies and now edits the journal of the Mega Society, also reports having joined to find people more like himself.

Others do it for the challenge. "I joined Prometheus just to see if I could," Simpson says. He now deals with the society's membership requests. He receives about two or three a week, although only three or four new members are accepted every year. The admissions process for these societies usually hinges on a score on an approved test, some of which have names such as Mega or Titan. Typical questions include analogies, the manipulation of complex three-dimensional shapes, or word problems that must be translated into equations.

Critics question whether IQ tests measure intelligence accurately, but "genius" societies rarely claim to represent true genius: the merging of intellect, creativity and outstanding achievement. Peters notes that her high-IQ colleagues are acutely aware of their own ignorance. Simpson concurs. "None of us consider ourselves a 'genius,'" he says. "Well, maybe there's this one guy, but he hasn't been in the society for a while now."

**International Society for Philosophical Enquiry** 1/1,000

**One in a Thousand Society** 1/1,000

**Vertex Society** 1/11,000

**Prometheus Society** 1/11,000

**Mega Society** 1/1,000,000

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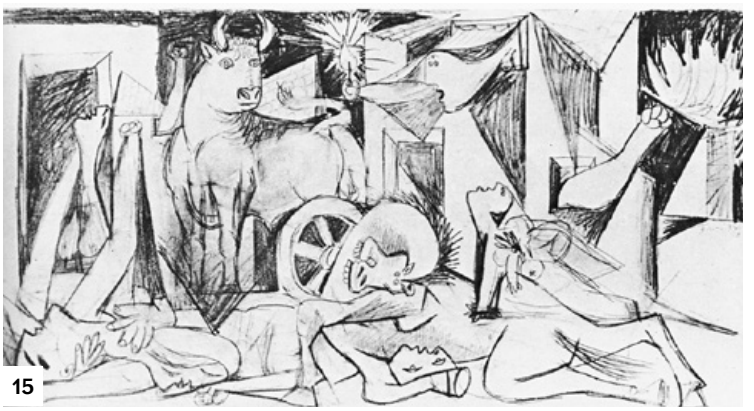
# Pablo Picasso's Chaotic Process

**In dozens of sketches** for his painting *Guernica*, Picasso explored numerous styles. A sampling of his drawings of the bull (*shown with Picasso's original numbering*) reveals the breadth of his exploration. Hunting widely for answers, abandoning some ideas and backtracking to earlier concepts (*red circle*) are hallmarks of a theory of creativity known as blind variation and selective retention.



*neuregulin 1* gene. In this study, Kéri recruited a group of highly creative individuals and found that the participants who had this specific gene variant, which is linked with an increased risk of developing a mental disorder, also scored higher on measures of creativity.

Out-and-out psychosis, however, can shut down creative genius. This tragic reality was dramatically illustrated in the 2001 film *A Beautiful Mind,* the biopic about the late Nobel laureate John Nash and his struggles with schizophrenia. The costs and burdens of psychological dysfunction are also immediately apparent in the art of the mentally ill, such as the works preserved in the Prinzhorn Collection in Heidelberg, Germany, done by psychiatric patients in the early 20th century. Few if any of these artworks show signs of genius. To quote Dryden again, "wits are sure to madness near allied, and thin partitions do their bounds divide."

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Research conducted by psychologist Shelley Carson of Harvard University and her colleagues sought to identify these thin partitions. Creative achievement is positively associated both with cognitive disinhibition—openness to supposedly extraneous ideas, images or stimuli—and higher intelligence and greater working memory. These mental capacities can potentially ameliorate the negative effects of cognitive disinhibition and even channel them to more useful ends. This synergy may well constitute the cognitive basis for serendipity. Not everybody would be able to work out the profound implications of such humdrum events as water overflowing a bathtub or an apple falling from a tree. But Archimedes and Newton did.

## THINKING OUTSIDE THE BOX

ARCHIMEDES AND NEWTON both worked in scientific fields, raising the possibility that their brands of creativity may have been similar. A more revealing question might be to investigate how their route to original thought compares with that of a superlative writer or musician. A physicist's way of thinking has little, if anything, in common with that of a painter. For example, learning how to solve a differential equation has as much utility for a painter as learning linear perspective has for a physicist—zero in most cases. Yet the themes uniting geniuses, as discussed earlier, suggest that a common creative principle may exist. Domain expertise, such as the knowledge of advanced problem-solving strategies, supports thinking that is routine, even algorithmic—it does not inherently lead to the generation of novel, useful and surprising ideas. Something else must permit a person to go beyond tradition and training to reach the summit of genius.

According to a theory proposed in 1960 by psychologist Donald Campbell, creative thought emerges through a process or procedure he termed blind variation and selective retention (BVSR). In short, a creator must try out ideas that might fail before hitting on a breakthrough. Campbell did not precisely define what counts as a blind variation, nor did he discuss in any detail the psychological underpinnings of this process. As a result, his ideas were left open to criticism.

Using a mixture of historical analyses, laboratory experiments, computer simulations, mathematical models and case studies, I have developed BVSR into a comprehensive theory of creative genius in all domains. The blindness of BVSR merely means that ideas are produced without foresight into their eventual utility. The creator must engage in trial-and-error or generate-and-test procedures to determine the worth of an idea. Two common phenomena characterize BVSR thinking: superfluity and backtracking. Superfluity means that the creator generates a variety of ideas, one or more of which turn out to be useless. Backtracking signifies that the creator must often return to an earlier approach after blindly going off in the wrong direction. Superfluity and backtracking are often found together in the same creative episode. Exploring the wrong track obliges a return to options that had been originally cast aside.

The reflections of Hermann von Helmholtz, a prolific physicist with numerous creative breakthroughs to his name, capture this process of discovery:

> I had to compare myself with an Alpine climber, who, not knowing the way, ascends slowly and with toil, and is often compelled to retrace his steps because his progress is stopped; sometimes by reasoning, and sometimes by accident, he hits upon traces of a fresh path, which again leads him a little further; and finally, when he has reached the goal, he finds to his annoyance a royal road on which he might have ridden up if he had been clever enough to find the right starting point at the outset.

This account of venturing blindly into uncharted territory and retracing steps resonates with evidence from other eminent creators. As Einstein once said, "If we knew what we were doing, we wouldn't call it research."

To see superfluity and backtracking in practice, consider the sketches that Pablo Picasso produced in preparation for his 1937 *Guernica* painting. Among them are clearly "superfluous" sketches, which have a human head on a bull's body (for example, sketches 19 and 22—using Picasso's original numbering—on the opposite page). Picasso soon discovered that this was a dead end and backtracked to an earlier bull's head drawing (15), before continuing to the final two sketches (26 and 27). Notice that the artist went too far in one direction in the last sketch, from which he backtracked yet again. Even more telling, after that last sketch Picasso largely reversed himself to a much earlier formulation (11), which shares the most unique features with the final version: the widely separated eyes, the thin-lipped open mouth with tongue, the menacing rather than inert visage and the cubist rather than neoclassical style. These sketches are typical of blind variations both in the arts and in the sciences.

Only further research can expand the theory into a comprehensive, predictive model whose claims can be thoroughly tested. Even so, BVSR can help us make sense of certain quirks of creative geniuses, including their personality traits and developmental experiences. Although they devote considerable time to achieving expertise, they also pursue other hobbies. Their openness to new ideas and their breadth of interests infuse them with seemingly irrelevant stimulation that can enrich blind variations.

As 19th-century German philosopher Arthur Schopenhauer said, "Talent hits a target no one else can hit; genius hits a target no one else can see." Exceptional thinkers, it turns out, stand on common ground when they launch their arrows into the unknown. SA

**Dean Keith Simonton** is Distinguished Professor Emeritus of Psychology at the University of California, Davis. He has published more than 500 articles and chapters, plus a dozen books, including *The Wiley Handbook of Genius* (Wiley-Blackwell, 2014).

### MORE TO EXPLORE

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**Creativity and Discovery as Blind Variation: Campbell's (1960) BVSR Model after the Half-Century Mark.** D. K. Simonton in *Review of General Psychology,* Vol. 15, No. 2, pages 158–174; June 2011.

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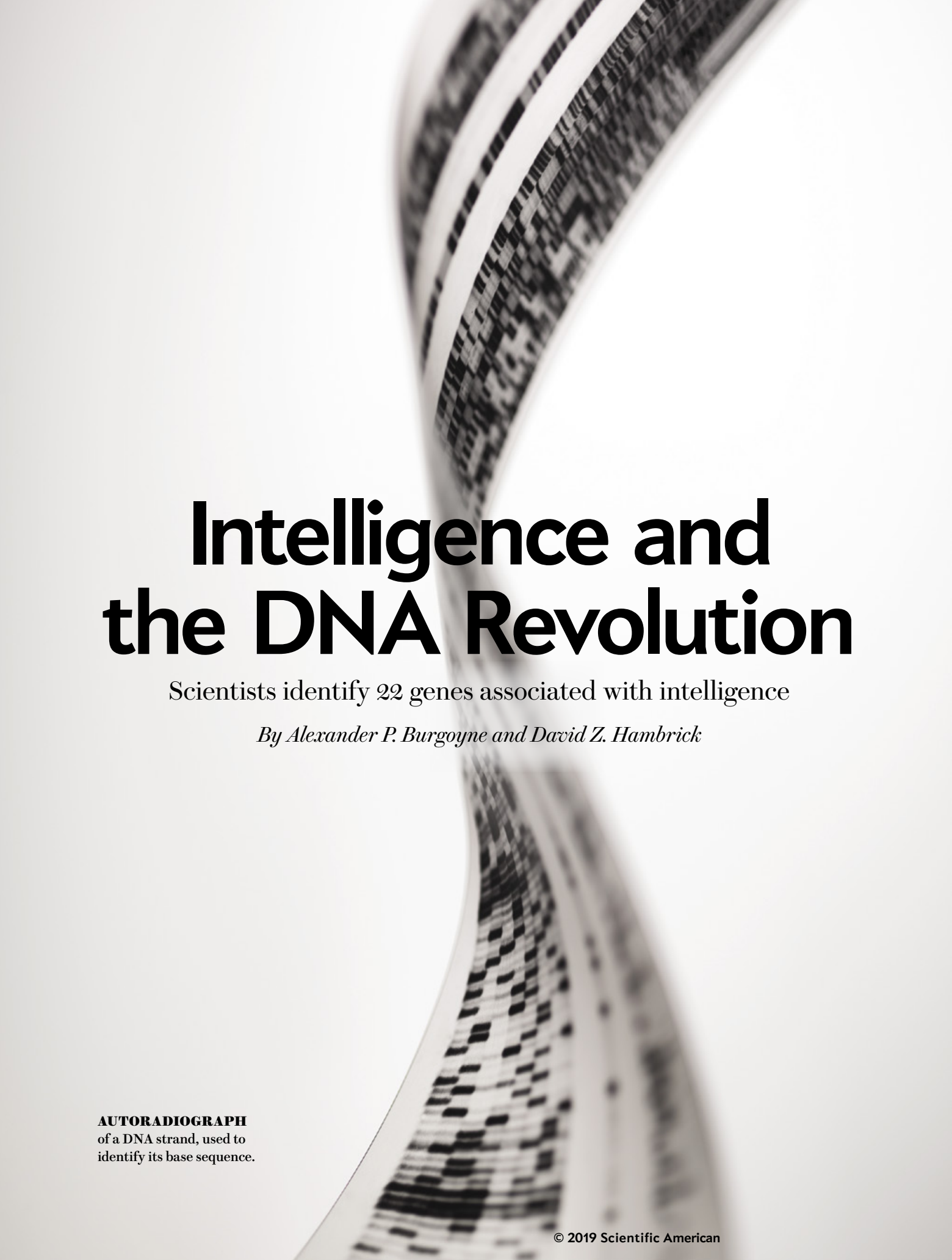

# Intelligence and the DNA Revolution

Scientists identify 22 genes associated with intelligence

*By Alexander P. Burgoyne and David Z. Hambrick*

**AUTORADIOGRAPH**
of a DNA strand, used to identify its base sequence.

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MORE THAN 60 YEARS AGO FRANCIS CRICK AND JAMES WATSON DISCOVERED the double-helical structure of deoxyribonucleic acid—better known as DNA. Today, for the cost of a one-year Netflix subscription, you can have your DNA sequenced to learn about your ancestry and proclivities. Yet while it is an irrefutable fact that the transmission of DNA from parents to offspring is the biological basis for heredity, we still know relatively little about the specific genes that make us who we are.

That is changing rapidly through genome-wide association studies—GWAS, for short. These studies search for differences in people's genetic makeup—their "genotypes"—that correlate with differences in their observable traits—their "phenotypes." In a GWAS published in *Nature Genetics,* a team of scientists from around the world analyzed the DNA sequences of 78,308 people for correlations with general intelligence, as measured by IQ tests.

The major goal of the study was to identify single-nucleotide polymorphisms—or SNPs—that correlate significantly with intelligence test scores. Found in most cells throughout the body, DNA is made up of four types of molecules called nucleotides, referred to by their organic bases: cytosine (C), thymine (T), adenine (A) and guanine (G). Within a cell, DNA is organized into structures called chromosomes. Humans normally have 23 pairs of chromosomes, with one in each pair inherited from each parent.

A SNP (pronounced "snip") is a nucleotide at a particular chromosomal region that can differ across individuals. For example, one person might have the nucleotide triplet TAC, whereas another might have TCC, and this variation may contribute to differences between the people in a trait such as intelligence. Genes consist of much longer nucleotide sequences and act as instructions for making proteins—the basic building blocks of life.

Of the more than 12 million SNPs analyzed, 336 correlated significantly with intelligence, implicating 22 different genes. One of the genes is involved in regulating the growth of neurons; another is associated with intellectual disability and cerebral malformation. Together the SNPs accounted for about 5 percent of the differences across people in intelligence—a nearly twofold increase over the last GWAS on intelligence. Examining larger patterns of SNPs, the researchers discovered an additional 30 genes related to intelligence.

As a check on the replicability of their results, the scientists then tested for correlations between the 336 SNPs and level of education—a variable known to be strongly correlated with intelligence—in an independent sample of nearly 200,000 people who had previously undergone DNA testing. Ninety-nine percent of the time, the SNPs correlated in the same direction with education as they did with intelligence. This finding helps to allay concerns that the SNPs associated with intelligence were false positives—in other words, caused by chance. More substantively, the finding adds to the case that some of the same processes underlie intelligence and learning. The authors concluded that the results "provide starting points for understanding the molecular neurobiological mechanisms underlying intelligence, one of the most investigated traits in humans."

In a 2018 study, researchers estimated the genetic contribution to intellectual giftedness by analyzing DNA samples from 1,238 people recruited from the Duke University Talent Identification Program, a nonprofit organization dedicated to identifying and fostering the development of academically talented children. The average IQ for the general population is 100; the average for this group was around 170, putting them in the top 0.03 percent. The idea behind the study was that if many genetic variants contribute to high intelligence, then these people would possess more of those genetic variants than those with lower IQs. The results supported this speculation: the sequenced SNPs explained 33 percent of a person's membership in this ultrahigh IQ group versus a control group with a normal range of IQ scores.

As neuroscientist Richard J. Haier discusses in his excellent book *The Neuroscience of Intelligence* (Cambridge University Press, 2017), other intelligence research is combining molecular genetic analyses and neuroimaging. In one study, using a sample of 1,583 adolescents, researchers discovered an SNP implicated in synaptic plasticity that was significantly related both to intelligence test scores and to cortical thickness, as measured by an MRI scan. In animal research, other investigators are using chemogenetic techniques to turn "on" and "off" neurons that may be important for intelligence.

Of course, intelligence is not solely the product of DNA—and no scientist studying it thinks otherwise. The environment has a major impact on the development of intelligence or any other psychological trait. All the same, knowledge gained from molecular genetic research may one day be used to identify children at risk for developing serious cognitive deficits and those for whom certain types of early interventions may reduce that risk. This research is also providing a scientific foundation for how brain functioning might be manipulated to enhance intelligence.

The big picture to emerge from research on the neurobiological underpinnings of intelligence and other psychological traits is that the nature-versus-nurture debate is, once and for all, over. We are a product of both our genetic makeup and our environment, as well as the complex interplay between the two. Research aimed at better understanding this interplay will give scientists a richer understanding of the similarities and differences in our psychological makeup. SA

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ANDREW BROOKES *Getty Images*



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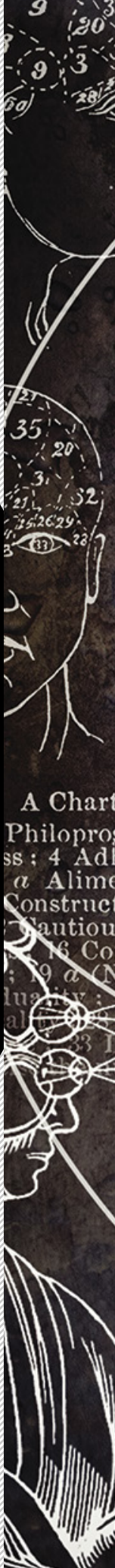
# DOES BRAIN SIZE MATTER?

**A recent discovery proves embarrassing to any notion of humanity's innate superiority**

*By Christof Koch*





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WHILE "SIZE DOES NOT MATTER" IS A UNIVERSALLY preached dictum among the politically correct, everyday experience tells us that this can't be the whole story—under many conditions, it clearly does. Consider the size of Woody Allen's second favorite organ, the brain. Adjectives such as "highbrow" and "lowbrow" have their origin in the belief, much expounded by 19th-century phrenologists, of a close correspondence between a high forehead—that is, a big brain—and intelligence. Is this true? Does a bigger brain make you necessarily smarter or wiser? And is there any simple connection between the size of a nervous system, however measured, and the mental powers of the owner of this nervous system? While the answer to the first question is a conditional "yes, somewhat," the lack of any accepted answer to the second query reveals our ignorance of how intelligent behavior comes about.

## BIGGER IS SLIGHTLY BETTER

THE HUMAN BRAIN continues to grow until it reaches its peak size in the third to fourth decade of life. An MRI study of 46 adults of mainly European descent found that the average male had a brain volume of 1,274 cubic centimeters ($cm^3$) and that the average female brain measured 1,131 $cm^3$. Given that a quart of milk equals 946 $cm^3$, you could pour a bit more than that into a skull without any of it spilling out. Of course, there is considerable variability in brain volume, ranging from 1,053 to 1,499 $cm^3$ in men and between 975 and 1,398 $cm^3$ in women. As the density of brain matter is just a little bit above that of water plus some salts, the average male brain weighs about 1,325 grams, close to the proverbial three pounds often cited in U.S. texts.

Removing brains after their owners died revealed that Russian novelist Ivan Turgenev's brain broke the two-kilogram barrier, coming in at 2,021 grams, whereas writer Anatole France's brain could barely bring half of that weight to the scale at 1,017 grams. (Note that postmortem measures are not directly comparable to data obtained from living brains.) In other words, gross brain size varies considerably across healthy adults.

What about smarts? We all know from our day-to-day interactions that some people just don't get it and take a long time to understand a new concept; others have great mental powers, although it is impolite to dwell on such differences too much. Think of Bertie Wooster, an idle but clueless rich man, and Jeeves, his genius valet, in a series of novels by P. G. Wodehouse and their successful British adaptation to the small screen.

IN BRIEF

**Human brains** vary considerably in size across adults, with males having slightly larger brains than females.
**It is hard to** pin down what makes the human brain exceptional among mammals—neither brain size, relative brain size nor number of neurons is unique to humans.
**More intelligent people** do better in life, but there is only weak correlation between brain size and intelligence, especially across species.

PRECEDING PAGE: ALAMY



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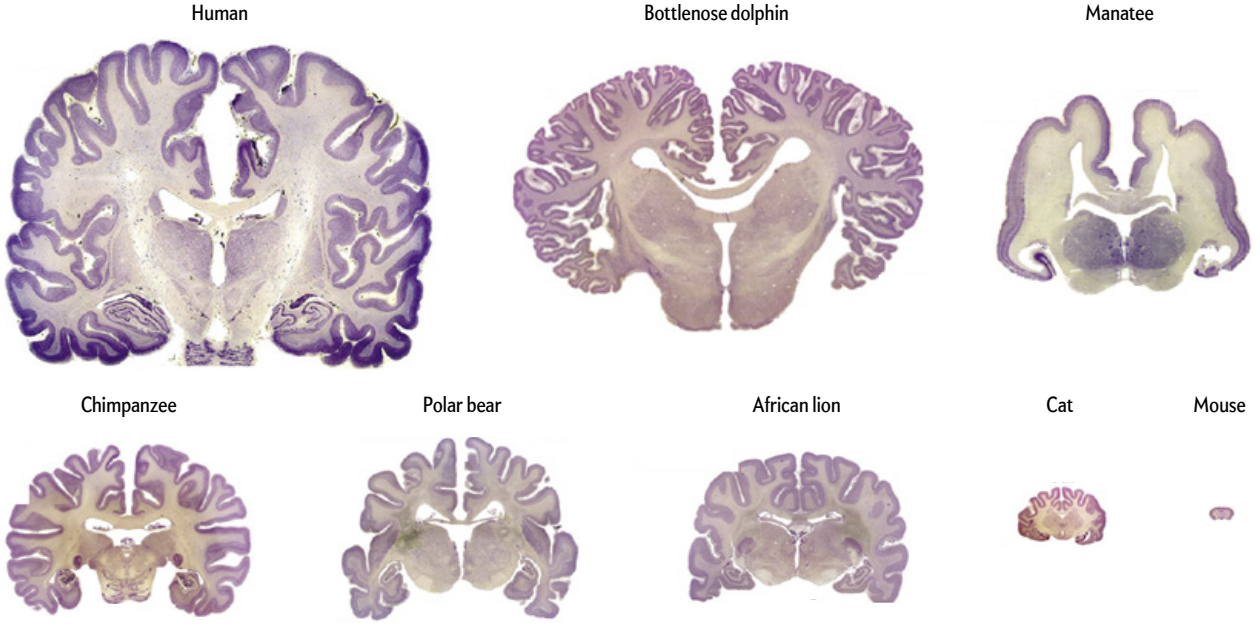
# From Man to Mouse

**Frontal slices** of eight mammalian brains reveal the immense variety in the size of the organ and the patterning of surface convolutions that have evolved over the course of tens of millions of years. The smoothness of the manatee's brain surface contrasts with the cauliflowerlike branching in the bottlenose dolphin. Structural differences extend down to the microscopic scale. Scientists are still laboring to understand what the varying anatomy means for animal intelligence.




Individuals differ in their ability to understand new ideas, to adapt to new environments, to learn from experience, to think abstractly, to plan and to reason. Psychologists have sought to capture these differences in mental capacities via a number of closely related concepts such as general intelligence (*g,* or general cognitive ability) and fluid and crystalline intelligence. These differences in people's ability to figure things out on the spot and to retain and apply insights that they learned in the past to current circumstances are assessed by psychometric intelligence tests. These observations are reliable, in that different tests strongly correlate with one another. They are also stable across decades. That is, measures such as the intelligence quotient (IQ) can be repeatedly and reliably obtained from the same subjects nearly 70 years later.

Differences in general intelligence, assessed in this way, correlate with success in life, with social mobility and job performance, with health and with life span. In a study of one million Swedish men, an increase in IQ by one standard deviation, a measure of variability, was associated with an amazing 32 percent reduction in mortality. Smarter people do better in life. Whereas a high IQ may not predispose people to be happy or to understand the finer points of dating, the highly intelligent are more likely to be found among hedge fund managers than among supermarket checkout clerks.

What about any numerical relation between brain size and intelligence? Such correlations were difficult to establish in the past when only pathologists had access to skulls and their content. With structural MRI imaging of brain anatomy, such measurements are now routine. In healthy volunteers, total brain volume weakly correlates with intelligence, with a correlation value between 0.3 and 0.4 out of a possible 1.0. In other words, brain size accounts for between 9 and 16 percent of the overall variability in general intelligence. Functional scans, used to look for brain areas linked to particular mental activities, reveal that the parietal, temporal and frontal regions of the cortex, along with the thickness of these regions, correlate with intelligence but, again, only modestly so. Thus, on average, a bigger brain is associated with somewhat higher intelligence. Whether a big brain causes high intelligence or, more likely, whether both are caused by other factors remains unknown.

SOURCE: "THE EVOLUTION OF THE BRAIN, THE HUMAN NATURE OF CORTICAL CIRCUITS, AND INTELLECTUAL CREATIVITY," BY JAVIER DEFELIPE, IN *FRONTIERS IN NEUROANATOMY*, VOL. 5, ARTICLE NO. 29; MAY 16, 2011



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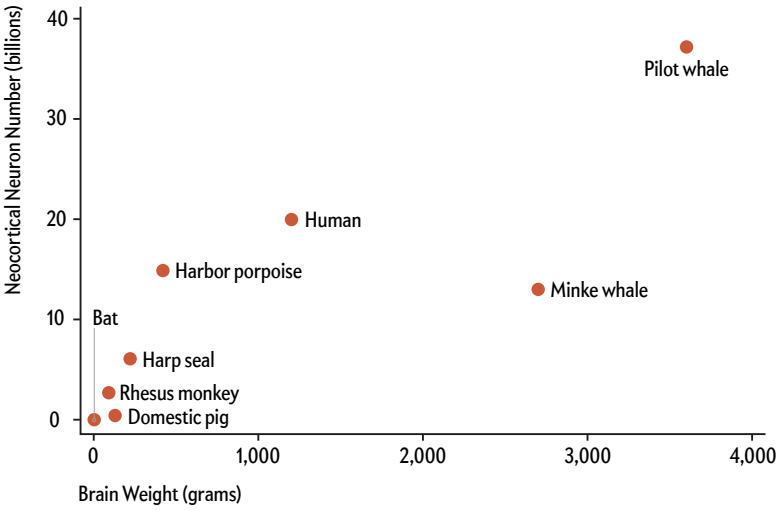
## Who Has the Most Brain Cells?



**The long-finned pilot whale** appears to have more neurons in the neocortex—an area devoted to higher mental processes—than any other mammal, about twice the number found in the human cortex. This type of dolphin and its massive brain are shown in the two images.

Recent experiments take into account the particular connections among neurons in certain regions of an individual's brain, much like a neural fingerprint. They do better at predicting fluid intelligence (the capacity to solve problems in novel situations, to find and match patterns, to reason independently of specific domains of knowledge), explaining about 25 percent of the variance in this measure from one person to the next.

Our ignorance when it comes to how intelligence arises from the brain is accentuated by several further observations. As alluded to earlier, the adult male's brain is 150 grams heavier than the female's organ. In the neocortex, the part of the forebrain responsible for perception, memory, language and reasoning, this disparity translates to 23 billion neurons for men versus 19 billion for women. As no difference exists in the average IQ between the two genders, why is there a difference in the basic number of switching elements?

**THE LONG-FINNED DOLPHIN APPEARS TO HAVE MORE NEURONS IN THE NEOCORTEX THAN ANY OTHER MAMMAL.**

It is also well established that the cranial capacity of *Homo neanderthalensis,* the proverbial caveman, was 150 to 200 $cm^3$ bigger than that of modern humans. Yet despite their larger brain, Neandertals became extinct between 35,000 and 40,000 years ago, when *Homo sapiens* shared their European environment. What's the point of having big brains if your small-brained cousins outcompete you?

### BRAIN SIZE ACROSS SPECIES

OUR LACK OF UNDERSTANDING of the multiplicity of causes that contribute to intelligence becomes even more apparent when we look outside the genus *Homo*. We observe that many animals are capable of sophisticated behaviors, including sensory discrimination, learning, decision-making, planning and highly adaptive social behaviors.

Consider honeybees. They can recognize faces, communicate the location and quality of food sources to their sisters via the waggle dance, and navigate complex mazes with the help of cues they store in short-term memory. And a scent blown into a hive can trigger a return to the site where the bees previously encountered this odor, a type of associative memory that guides them back and that was made famous by Marcel Proust in his *Remembrance of Things Past* (*À la Recherche du Temps Perdu*). The

SOURCE: "QUANTITATIVE RELATIONSHIPS IN DELPHINID NEOCORTEX," BY HEIDI S. MORTENSEN ET AL., IN *FRONTIERS IN NEUROANATOMY*, VOL. 8, ARTICLE NO. 132. PUBLISHED ONLINE NOVEMBER 26, 2014 (*chart*); HEIDI S. MORTENSEN (*brain*); ÓLAVUR FREDERIKSEN (*pilot whale*)



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insect does all of this with fewer than one million neurons that weigh around one thousandth of a gram, less than one millionth the size of the human brain. Yet are we really a million times smarter? Certainly not if I look at how well we govern ourselves.

The prevailing rule of thumb holds that the bigger the animal, the bigger its brain. After all, a bigger creature has more skin that has to be innervated and more muscles to control and requires a larger brain to service its body. Thus, it makes sense to control for overall size when studying brain magnitude. By this measure, humans have a relative brain-to-body mass of about 2 percent. What about the big mammals—elephants, dolphins and whales? Their brains far outweigh those of puny humans, up to 10 kilograms for some whales. Given their body mass, ranging from 7,000 kg (for male African elephants) up to 180,000 kg (for blue whales), their brain-to-body ratio is under a tenth of a percent. Human brains are far bigger relative to people's sizes than those of these creatures. Smugness is not in store, though. We are outclassed by shrews, molelike mammals, whose brain takes up about 10 percent of their entire body mass. Even some birds beat us on this measure. Hmm.

**A STUDY OF PILOT WHALES PLAYS HAVOC WITH THE NOTION THAT HUMANS HAVE MORE NERVE CELLS WHERE IT COUNTS THAN ANY OTHER SPECIES ON THE PLANET.**

One small consolation is an invention of neuroanatomists called the encephalization quotient (EQ). It is the ratio of the mass of the brain of the species under investigation relative to a standard brain belonging to the same taxonomic group. Thus, if we consider all mammals and compare them against the cat as a reference animal (which therefore has an EQ of 1), people come out on top with an EQ of 7.5. Stated differently, the human brain is 7.5 times bigger than the brain of a typical mammal weighing as much as we do. Apes and monkeys come in at or below five, as do dolphins and other cetaceans. We finally made it to the top, validating our ineradicable belief in humanity's exceptionalism.

Yet it is not quite clear what all this means in terms of the cellular constituents of brains. Neuroscientists always assumed that humans have more nerve cells where it counts, in the neocortex, than any other species on the planet, no matter the size of their brain.

A 2014 study of 10 long-finned pilot whales from the Faeroe Islands plays havoc with this hypothesis. Caught as part of a local hunt in the cold waters of the North Atlantic between Scotland and Iceland, these graceful mammals—also known as blackfish—are actually dolphins. The number of nerve cells making up their highly convolved neocortex was estimated in a few sample slices and then extrapolated to the entire structure. The total came to an astonishing 37.2 billion neurons. Astonishing because this implies that the long-finned pilot whale has about twice as many neocortical neurons as humans do!

If what matters for cognitive performance is the number of neocortical neurons, these dolphins should be smarter than all other extant creatures, including us. Whereas the highly playful and social dolphins exhibit a variety of skills, including the ability to recognize themselves in a mirror, they do not possess language or any readily discernible powers of abstraction that stand out from those of other nonhuman animals. So what gives? Is the complexity of the nerve cells themselves substantially less than cells found in people, or is the way these neurons communicate or learn less sophisticated? We don't know.

People forever ask for *the* single thing that distinguishes humans from all other animals, on the supposition that this one magical property would explain our evolutionary success—the reason we can build vast cities, put people on the moon, write *Anna Karenina* and compose *Eroica*. For a while it was assumed that the secret ingredient in the human brain could be a particular type of neuron, so-called spindle or von Economo neurons, named for Baron Constantin von Economo (1876–1931).

But we now know that not only great apes but also whales, dolphins and elephants have these neurons in their frontal cortex. So it is not brain size, relative brain size or absolute number of neurons that distinguishes us. Perhaps our wiring has become more streamlined, our metabolism more efficient, our synapses more sophisticated.

As Charles Darwin surmised, it is very likely a combination of a great many different factors that jointly, over the gradual course of evolution, made us distinct from other species. We are unique, but so is every other species, each in its own way. SA

**Christof Koch** is president and chief scientific officer of the Allen Institute for Brain Science in Seattle. He serves on *Scientific American*'s board of advisers.

MORE TO EXPLORE

**The Evolution of the Brain, the Human Nature of Cortical Circuits, and Intellectual Creativity.** Javier DeFelipe in *Frontiers in Neuroanatomy,* Vol. 5, Article No. 29. Published online May 16, 2011.

**Quantitative Relationships in Delphinid Neocortex.** Heidi S. Mortensen et al. in *Frontiers in Neuroanatomy,* Vol. 8, Article No. 132. Published online November 26, 2014.

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# Why Do Smart People Do Foolish Things?

## Intelligence is not the same as critical thinking—and the difference matters

*By Heather A. Butler*

We all probably know someone who is intelligent but does surprisingly stupid things. My family delights in pointing out times when I (a professor) make really dumb mistakes. What does it mean to be smart or intelligent? Our everyday use of the term is meant to describe someone who is knowledgeable and makes wise decisions, but this definition is at odds with how intelligence is traditionally measured. The most widely known measure of intelligence is the intelligence quotient, more commonly known as the IQ test, which includes visuospatial puzzles, math problems, pattern recognition, vocabulary questions and visual searches.

The advantages of being intelligent are undeniable. Intelligent people are more likely to get better grades and go farther in school. They are more likely to be successful at work. And they are less likely to get into trouble (for example, commit crimes) as adolescents. Given all the advantages of intelligence, though, you may be surprised to learn that it does not predict other life outcomes, such as well-being. You might imagine that doing well in school or at work might lead to greater life satisfaction, but several large-scale studies have failed to find evidence that IQ impacts life satisfaction or longevity. University of Waterloo psychologist Igor Grossmann and his colleagues argue that most intelligence tests fail to capture real-world decision-making and our ability to interact well with others. This is, in other words, perhaps why "smart" people do "dumb" things.

The ability to think critically, on the other hand, *has* been associated with wellness and longevity. Though often confused with intelligence, critical thinking is not intelligence. Critical thinking is a collection of cognitive skills that allow us to think rationally in a goal-orientated fashion and a disposition to use those skills when appropriate. Critical thinkers are amiable skeptics. They are flexible thinkers who require evidence to support their beliefs and recognize fallacious attempts to persuade them. Critical thinking means overcoming all kinds of cognitive biases (for instance, hindsight bias or confirmation bias).

Critical thinking predicts a wide range of life events. In a series of studies, conducted in the U.S. and abroad, my colleagues and I have found that critical thinkers experience fewer bad things in life. We asked people to complete an inventory of life events and take a critical thinking assessment (the Halpern Critical Thinking Assessment). The critical thinking assessment measures five components of critical thinking skills, including verbal reasoning, argument analysis, hypothesis testing, probability and uncertainty, decision-making and problem-solving.

The inventory of negative life events captures different domains of life such as academic (for example, "I forgot about an exam"), health ("I contracted a sexually transmitted infection because I did not wear a condom"), legal ("I was arrested for driving under the influence"), interpersonal ("I cheated on my romantic partner who I had been with for more than a year"), financial ("I have over $5,000 of credit-card debt"), and so on. Repeatedly, we found that critical thinkers experience fewer negative life events. This is an important finding because there is plenty of evidence that critical thinking can be taught and improved.

Is it better to be a critical thinker or to be intelligent? My latest research pitted critical thinking and intelligence against each other to see which was associated with fewer negative life events. People who were strong on either intelligence or critical thinking experienced fewer negative events, but critical thinkers did better.

Intelligence and improving intelligence are hot topics that receive a lot of attention. It is time for critical thinking to receive a little more of that attention. Keith E. Stanovich wrote an entire book in 2009 about *What Intelligence Tests Miss*. Reasoning and rationality more closely resemble what we mean when we say a person is smart rather than spatial skills and math ability. Furthermore, improving intelligence is difficult. Intelligence is largely determined by genetics. Critical thinking, though, can improve with training, and the benefits have been shown to persist over time. Anyone can improve their critical thinking skills. Doing so, we can say with certainty, is a smart thing to do. SA

**Heather A. Butler** is an assistant professor in the psychology department at California State University, Dominguez Hills. Her numerous research interests include critical thinking, advanced learning technologies, and the use of psychological science to prevent wrongful convictions.

GETTY IMAGES



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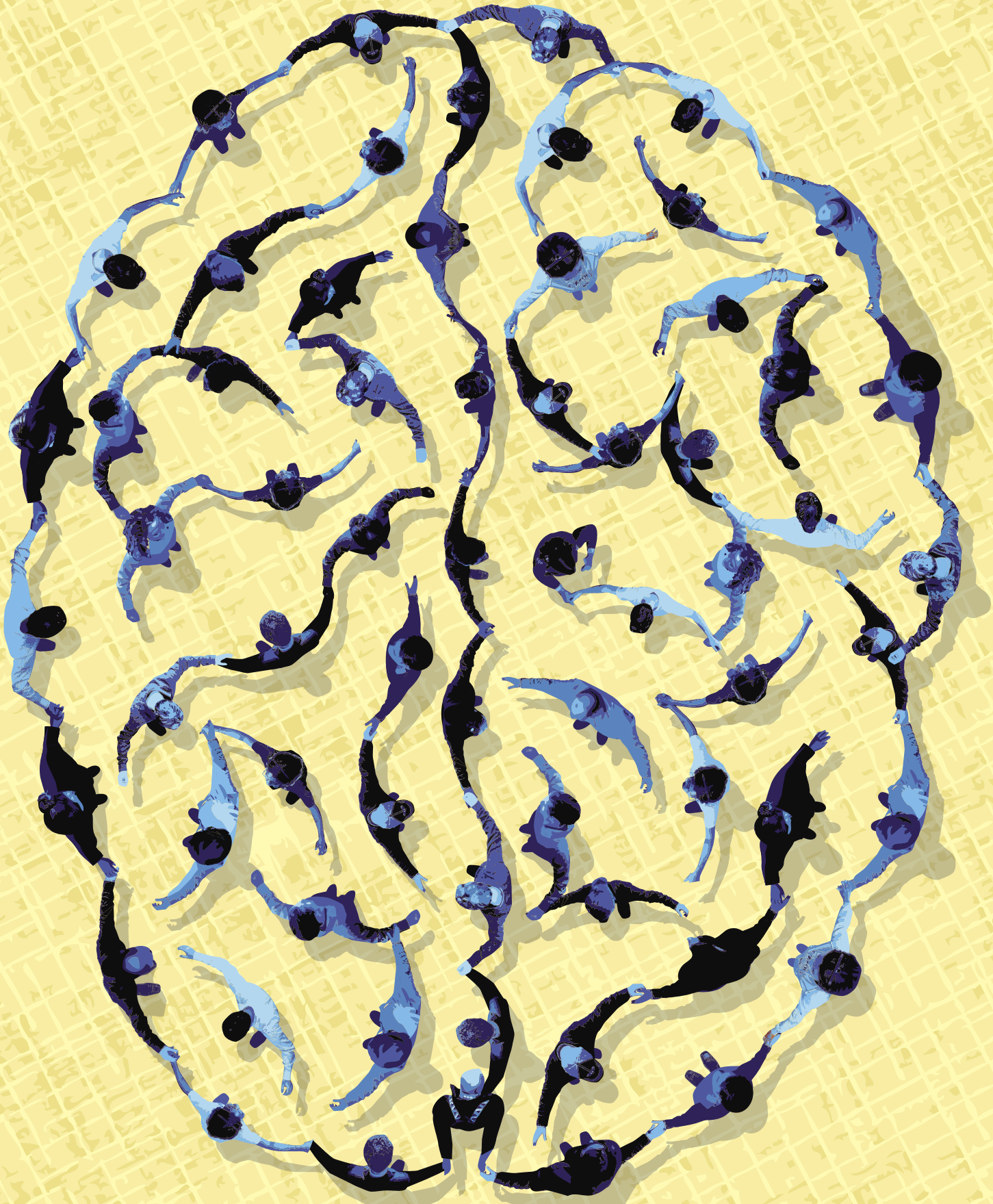

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# Creativity is Collective

Personal experiences and character traits alone may not be enough to produce a prodigy. It takes a village

*By S. Alexander Haslam, Inmaculada Adarves-Yorno and Tom Postmes*

*Illustration by Daniel Hertzberg*

IN BRIEF

**Groups play** an essential role in creativity—not only in shaping novel products themselves but also in ensuring their appreciation and impact.

**A sense** of shared social identity provides the motivation for people to stick to a creative project and see it to completion.

**People's** perceptions of creativity depend on whether the creator is "one of us" or "one of them."



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THE BEST ACTORS, DIRECTORS AND SCREENWRITERS RECEIVE OSCARS; the top scientists, Nobel Prizes. Society doles out a multitude of awards every year to celebrate the creative achievements of individuals. Such events feed a popular conception that creativity is a gift only certain people possess and constitutes the apotheosis of individuality. Albert Einstein once observed, "Everything that is really great and inspiring is created by the individual who can labor in freedom." In these terms, the straitjacket of groups and of mainstream society is often thought to spell death for creativity. Many see the notion of group creativity as an oxymoron.

But let us think creatively here and challenge the basic assumption that the individual creator is the only critical component of the creative process. Indeed, let us consider the possibility that groups play an essential role in creativity—not only in generating and shaping novel products but also in ensuring their appreciation and impact. Although this idea might seem preposterous, it has garnered significant scientific support. The three of us, with our colleague Lise Jans, published a review of much of the accumulated data in an article summarizing the current thinking about groups and creativity. We concluded that it is problematic and unhelpful to separate the creativity of individual minds from the communities in which they flourish.

## SOCIAL IDENTITIES

DESPITE THE ROMANTIC NOTION that innovation is the province of rugged individuals slaving away in splendid isolation, a scientific focus on individual personality has not yet yielded accurate forecasts of creative behavior. Scholars have scoured the biographies of creative geniuses to find experiences and character traits likely to have contributed to their greatness. Yet they have failed to identify characteristics that powerfully predict which young people will go on to become creative geniuses.

These efforts lack predictive power because they do not take into account the important role that social context plays. The nature and significance of innovation depend on the interaction between an individual's ideas and the time and culture in which he or she lives. If Bruce Springsteen had been born in 1749 rather than 1949, we would have been unlikely ever to hear *Born to Run*. Likewise, if Italian composer Domenico Cimarosa had been born in 1949 rather than 1749, his nearly 80 operas, including the masterpiece *Il matrimonio segreto,* probably would not have seen the light of day.

Such examples speak more generally to the influence that groups exert on creativity. In the 1970s psychologists Henri Tajfel and John Turner of the University of Bristol in England developed the concept of social identity, observing that across a range of contexts, people understand themselves not only as individuals but also as members of the groups to which they belong. So a cubist painter—we'll call him "Pablo"—may sometimes think of himself in terms of his personal identity (Pablo), but on other occasions he will understand himself as a cubist, his social identity. In yet other situations, his social identity might be defined with reference to his nationality, gender or religion or to his role in a specific team, club or organization.

Tajfel and Turner argued that when a particular social identity is psychologically salient, such that it determines a person's sense of who he or she is, the group that is the basis for that identity will exert a profound influence on that individual's



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behavior. Furthermore, the way in which that person evaluates an action, regardless of whether it is his or her own, will reflect shared understandings of that group. This idea also applies to creative behavior and its evaluation. For example, as a cubist, Pablo is more likely to be interested in and to appreciate abstract representations of objects, and he will be more likely to paint in accordance with cubist guidelines and preferences.

Social identities also grant people a shared perspective, as well as the ability and motivation to engage in mutual social influence. But when people act in terms of their unique personal identity, they are likely to display creativity by deviating from the norm. In an experiment published in 2007, the three of us asked some college students, who were working in groups, to create posters about "reasons for going to university" and other groups of students to make posters about "fashion at university." With these instructions, we implicitly led the students toward certain group norms. Those told to focus on "reasons" naturally made posters dominated by words, and those directed toward "fashion" created posters populated largely by images.

In a second phase of the study, which came three hours later, we asked the same participants to create a leaflet to advertise the university, a task that could be accomplished equally well with words as with pictures. This time some of the students worked in groups, whereas others made the leaflet on their own. Here we were interested in whether this creative task would be shaped by the group norm that had been established in the earlier phase. It was. We found that when working in a group, participants' creations were generally in line with the group norm established during the poster-making project, whether it centered on images or words. When working individually, however, participants typically departed from the norm of the group they had previously belonged to. Such findings, and those of similar studies, support the claim that the nature of people's creative activity depends on group norms.

1

**MUSICAL GROUPS**—such as the Beatles (*above*)—as well as groups of writers, scientists and others, can fuel creativity when group members receive encouragement and constructive feedback from one another.

2

**EVEN RADICAL EFFORTS** to depart from the mainstream, such as those that were promulgated by punk rock band the Sex Pistols (*above*), get much of their momentum from the culture they reject.

## COLLABORATIVE SPIRIT

EVIDENCE THAT SOCIAL IDENTIFICATION shapes creativity might suggest that groups simply stimulate convergent thinking and conformity. Indeed, back in the 1970s, Irving Janis of Yale University proposed that a desire to conform to the group leads to a lack of critical thinking and faulty decision-making—a phenomenon called groupthink that he considered the antithesis of creativity. But although group dynamics can sometimes be

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stifling (or worse), they do not inevitably produce irrational choices or blind support of the group's ideas.

For one thing, group standards shape only one facet of an individual's creativity. Cubist painters, for instance, may use abstract geometric figures in line with the customs of cubism, but their artwork is likely to diverge on other dimensions—for example, in its use of certain colors or themes—that are not restrained by the cubist style.

In addition, far from repressing new ideas, collaborative discussions with friends, colleagues or peers can foster them. As the late psychologist Vera John-Steiner of the University of New Mexico noted in her 2000 book *Creative Collaboration,* small groups—the Beatles, Bauhaus or the Bloomsbury Group, for instance—routinely spearhead innovation by bouncing ideas off one another as they look for new ways to tackle artistic, theoretical and practical problems.

What is more, solidarity and conformity are essential for creative movements to progress because they allow individuals to cohere around a shared enterprise. In a study published in 2006, we explored this idea by asking small groups of college students to participate in a mock planning process directed at the building of an innovative municipal child care center. Prior to the study, some of the groups went through a procedure that instilled a strong sense of shared social identity, whereas other groups were encouraged to think of themselves as individuals. The groups then met three times over an hour and a half to discuss the fictitious project, which encountered mounting difficulties. First, labor costs increased, and then an environmental impact study was needed. Next, they learned that the children's sandbox had traces of toxic elements, parents were threatening to sue, and officials were holding up building approval.

We found that the groups that had initially developed a shared social identity stayed upbeat about the project and continued to support it even as it ran into trouble. On the other hand, those coaxed to see themselves as individuals lost their enthusiasm for the child care center and increasingly argued to abort the project as time went on. In other words, social—but not personal—identity bolstered enthusiasm and encouraged people to stay with the creative task in the face of challenges. More generally, people seem to need a sense of shared social identity to stick to their creative guns and see revolutionary projects—whether in science, industry, the arts or politics—to completion.

Being solidly committed to the group does not make a person blind to its faults, either. Sometimes the opposite appears to be the case. When norms are harmful for a group, it is actually the members who feel most connected to the group who are the most motivated to debate and renegotiate those norms. In research published in 2012, psychologists Dominic J. Packer of Lehigh University and Christopher T. H. Miners of Queen's University in Ontario asked students to write an opening statement before a meeting in which they were going to discuss alcohol use with their peers, among whom a tendency to party was the norm. The researchers found that the more the participants identified with the group, the more their statements involved creative challenges to that group norm, possibly because those high identifiers felt the greatest responsibility to the group or the most able to effect a transformation. Either way, the research shows that engagement with groups can help stimulate creative ideas for change.

**EVEN THE MOST** creative people need followers. The art of painter Vincent van Gogh (*self-portrait above*) received widespread recognition only after his death, when it inspired a burgeoning group of artists, the Postimpressionists.

## GETTING ATTENTION

GROUPS ALSO PLAY a vital role in the appreciation of groundbreaking achievements. Without tapping into group identity, innovative artists, writers and scientists may well go unrecognized. In his lifetime, Vincent van Gogh could find hardly anyone to buy his unusual paintings. His work garnered attention only when, after his death, a circle of artists, the Postimpressionists, saw his paintings as indicative of a distinctive style that they wanted to emulate in their own work. Similarly, in 1961 the computational models of then graduate student Yoshisuke Ueda were initially barred from publication by his supervisor at Kyoto University because they were seen to be too avant-garde. Once a community of scientists had formed who appreciated Ueda's work, however, his theories transformed the newly emerging field of chaos theory.

Indeed, people are far more likely to support a creative project or endeavor if its instigator is a member of their group. Such insider status helps to dispel the uncertainty that new products introduce by disrupting the status quo. Insiders in organizations are typically antagonistic toward outsiders' contributions, and people often display ethnocentric bias when judging artistic creativity as well. In the performing arts, judges may preferentially bestow accolades on citizens of their own country.

For example, both the U.S. Oscars and the British Academy of Film and Television Arts (BAFTA) awards are meant to judge the objective quality of films. But in an archival study published in 2017 in the *British Journal of Psychology,* psychologist Niklas Steffens and his colleagues at the University of Queensland in Australia found that since 1968, U.S. actors and actresses have received about 80 percent of the Oscars for best actor and best actress but less than half of the BAFTA awards for the same categories. At the same time, British performers have received nearly half the BAFTA awards for best actor or actress but just over 10 percent of the corresponding Oscars.

**WHEN NORMS ARE HARMFUL FOR A GROUP, IT IS THE MEMBERS WHO FEEL MOST CONNECTED TO THE GROUP WHO ARE THE MOST MOTIVATED TO DEBATE AND RENEGOTIATE THOSE NORMS.**

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Experiments confirm that people's perceptions of creativity depend on whether the creator is "one of us" or "one of them." In one study published in 2008, the three of us asked 50 people from the U.K. to evaluate suggestions about the future format of a television show that we said had come from a British Web site. We told another 50 participants that the same ideas had come from a Dutch Web site. In part two of the study, we asked 125 British students to evaluate works of art that we attributed to either British or Dutch college students. In both cases, participants who thought their fellow Brits, the in-group, had authored the products in question judged them to be significantly more creative than did those told that Dutch citizens had generated the same items.

What people actually mean by creativity—and hence how they measure and reward it—also depends on cultural identity. In work published in 2008, psychologists Susannah Paletz, now at the University of Maryland, and Kaiping Peng of the University of California, Berkeley, conducted a survey that included more than 300 students from China and the U.S. to find out what they thought made certain products creative. They tested two very different types of products: a course textbook and a meal cooked by a friend. They found that American students' judgments of creativity were swayed more by the perceived appropriateness of a product (whether it was, in some sense, good), whereas the judgments of Chinese students were based more on whether the product was something they personally desired. The Americans thus saw creativity more as a matter of taste, and the Chinese saw it more as a matter of appetite.

The tendency for creativity judgments to reflect our social identities also explains some gender bias. In a 2006 paper, psychologist Thomas Morton and his colleagues at the University of Exeter in England reported that male scientists viewed theories explaining how men were superior to women to be better and more creative than those arguing that women were superior to men. This pattern was reversed for female scientists. Both groups also believed that the creative research that supported their own identity-based preferences was deserving of more research funding.

For their part, good creators have a strong sense of their audience and gear their solutions or products to the perceived needs and values of a particular group. Even when work is inspired by the need to separate from a group, a successful creator is familiar with the group from which he or she wishes to deviate.

For example, in the 1970s punk rock bands such as the Sex Pistols wanted to break away from mainstream popular music. Sid Vicious, the Sex Pistols's bassist, called on people to "undermine [the establishment's] pompous authority, reject their moral standards, make anarchy and disorder your trademarks." Ironically, then, the musical establishment of the time gave his band a particular creative force (the desire to rebel), as well as a specific trajectory (something specific to move away from) and appeal (for those disaffected with mainstream popular music). Accordingly, as with other successful creative efforts, the Sex Pistols's attempts to break the mold were not quite so random and anarchic as their progenitors would have us believe.

**PABLO PICASSO** (*above*) **likely thought of himself as a cubist painter as well as an antifascist and a Spaniard. Depending on the context, different social identities will influence our behavior.**

## TRANSFORMING COMMUNITIES

AS MEMBERS OF GROUPS, our creative behavior and evaluations of others' innovations reflect a desire to extend the values of those groups and to challenge the values of outsiders. To be celebrated rather than vilified, innovators need to know the norms they are departing from. Eventually they also need an audience willing to embrace the new ways of seeing or behaving made possible by their work. To meet with success, therefore, creative endeavors must transform communities. These newly formed audiences then drive the cultural change that novel endeavors spark.

Popular thinking on this topic, however, hews closer to Pablo Picasso's. "Disciples be damned," he once said. "It's only the masters that matter. Those who create." Yet as the curators of a major exhibition at London's National Gallery noted in 2009, Picasso's own work owed much to earlier modes of painting that he eventually rejected, and without admirers his work would have had little influence on society. His work was therefore not about laboring on his own to create everything anew. Rather as Welsh painter Osi Rhys Osmond, who died in 2015, put it in a review of the exhibition, it was a collaborative exercise in "reinventing the familiar."

We should still study and celebrate the creative genius of individuals. Nevertheless, we need to recognize that the psychology of creativity also involves the groups in which creators develop their work, whose boundaries they seek to extend and through which they have their sway. "I did it my way" may be an appealing anthem for great creators, but as with Frank Sinatra, their success generally also requires promoters, producers and an approving public. SA

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**Tom Postmes** is a professor of social psychology at the University of Groningen in the Netherlands.

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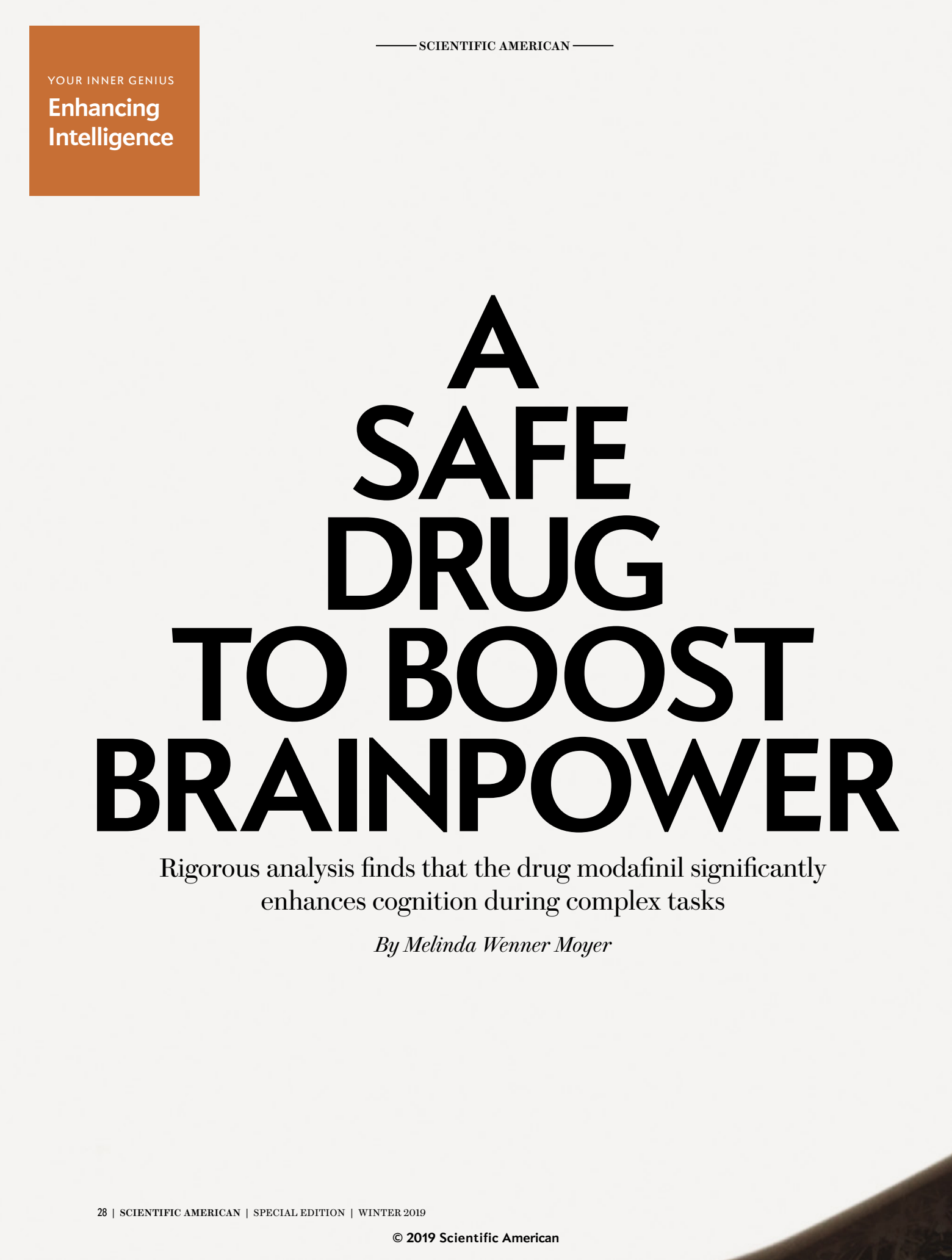
YOUR INNER GENIUS
**Enhancing Intelligence**

# A SAFE DRUG TO BOOST BRAINPOWER

Rigorous analysis finds that the drug modafinil significantly enhances cognition during complex tasks

*By Melinda Wenner Moyer*





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WHAT IF YOU COULD POP A PILL THAT MADE YOU SMARTER? It sounds like a Hollywood movie plot, but a new systematic review suggests that the decades-long search for a safe and effective "smart drug" [*see box below*] might have notched its first success. Researchers have found that modafinil boosts higher-order cognitive function without causing serious side effects. Modafinil, which has been prescribed in the U.S. since 1998 to treat sleep-related conditions such as narcolepsy and sleep apnea, heightens alertness much as caffeine does.

A number of studies have suggested that it could provide other cognitive benefits, but results were uneven. To clear up the confusion, researchers then at the University of Oxford analyzed 24 studies published between 1990 and 2014 that specifically looked at how modafinil affects cognition. In their review, which was published in 2015 in *European Neuropsychopharmacology,* they found that the methods used to evaluate modafinil strongly affected the outcomes. Research that looked at the drug's effects on

## Should Everyone Take Cognition-Enhancing Drugs?

As is the case with all medications, cognition-enhancing drugs affect different people in various ways. Setting aside the ethical questions about brain boosters, here is a look at groups who may deserve special consideration.

CHILDREN AND TEENS: Cognition-enhancing drugs could present unique risks to the developing brain. Several clinical trials found modafinil to be safe when given to children with attention-deficit/hyperactivity disorder (ADHD), but the trials lasted only a few months, making it difficult to ascertain the potential effects of long-term use. In a 2014 review article examining the biochemical effects of modafinil and other common "smart drugs," researchers at the University of Delaware and Drexel University raised concerns that the use of these drugs could affect the developing brain's ability to adapt to new situations and might increase the risk for addictive behaviors.

PEOPLE WITH LOWER IQs: Research suggests that cognition-enhancing drugs offer the greatest performance boost among individuals with low-to-average intelligence. These findings led University of Oxford researchers to propose in a 2014 paper that if such drugs were selectively given to people who need them most, many ethical concerns about the drugs' use would be alleviated, and they might even reduce opportunity inequality.

SENIORS: Some studies suggest that older adults may not derive much benefit from cognition-enhancing drugs. One study found that methylphenidate (Ritalin), which boosts working memory and attention in young adults, had no effect on performance among healthy elderly volunteers who were asked to perform various cognitive tasks. —*M.W.M.*

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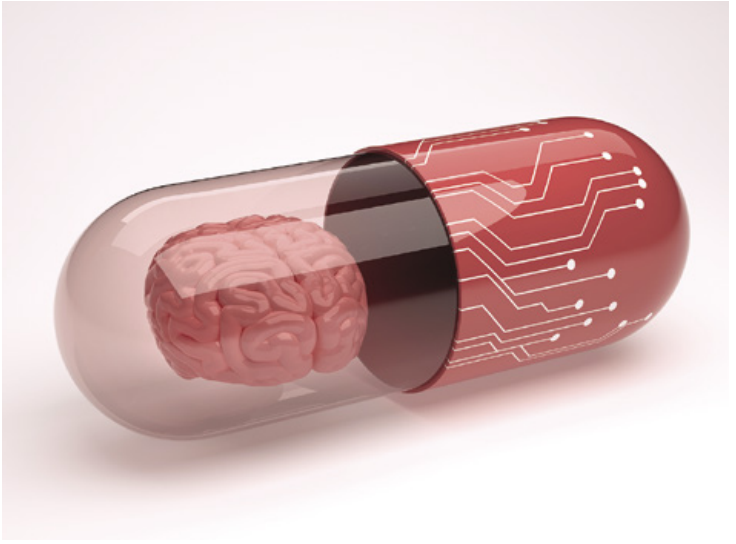

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the performance of simple tasks—such as pressing a particular button after seeing a certain color—did not detect many benefits.

Yet studies that asked participants to do complex and difficult tasks after taking modafinil or a placebo found that those who took the drug were more accurate, which suggests that it may affect "higher cognitive functions—mainly executive functions but also attention and learning," explains study co-author Ruairidh Battleday, now a medical doctor and Ph.D. student at the University of California, Berkeley.

But don't run to the pharmacy just yet. Although many doctors very likely prescribe the drug off-label to help people concentrate—indeed, a 2018 study found that 22 percent of Americans had taken prescription brain-boosting drugs in the past year and that 4.1 percent had used modafinil—trials have not yet been done on modafinil's long-term effectiveness or safety. Studies of the drug have been "carried out in a controlled scientific environment and usually only looked at the effects of a single dose," explains neuropsychologist and review co-author Anna-Katharine Brem, then at Oxford—so no one yet knows whether it is safe for long-term use in healthy people. Nor is it known whether modafinil might lose its edge with repeated use, a phenomenon familiar to many coffee drinkers.

Side effects are another important consideration. Modafinil has been shown to cause insomnia, headache and stomachache in select users, and some research suggests it could be addictive. Although these kinds of problems may be worth enduring for a drug that treats an illness, "if you don't have a medical condition, the risks versus benefits change dramatically," says Sharon Morein-Zamir, a psychologist at the University of Cambridge, who studies ethical considerations associated with the use of cognition-enhancing drugs. "For some the benefits will likely outweigh risks, at least some of the time," she says, whereas "for others this may not be the case." A pill you take to ace an exam, for instance, won't do you much good if it also causes a grueling stomachache. SA

Contributing editor **Melinda Wenner Moyer** won an Award for Excellence in Health Care Journalism for her December 2016 *Scientific American* article "The Looming Threat of Factory-Farm Superbugs."

## The Search for an Intelligence Drug

**People have been searching for ways** to boost their brainpower perhaps for all of history. In the past century scientific efforts have revealed a few promising chemicals, but only modafinil has passed rigorous tests of cognitive enhancement.

**CAFFEINE:** One of the oldest and most popular stimulants. People recognized caffeine's stimulant properties hundreds (perhaps thousands) of years ago. It can enhance alertness and attention; however, effects are short-lived, and tolerance builds up quickly.

**NICOTINE:** Also a stimulant, used for hundreds of years for a range of medicinal purposes. It is very addictive and has many dangerous side effects.

**AMPHETAMINE (BENZEDRINE, ADDERALL):** First synthesized in 1887. Benzedrine was the first drug to treat hyperactivity in children. Amphetamine can enhance attention and memory by increasing levels of norepinephrine and dopamine in the brain, but the compound can be addictive and comes with a range of side effects, including hyperactivity, loss of appetite, disturbed sleep, even psychosis.

**METHYLPHENIDATE (RITALIN):** First marketed in 1954 and prescribed in the 1960s for treating hyperactivity. It became popular for ADHD in the 1990s. As with amphetamine, it can improve memory and focus for those with ADHD, but it is also used off-label as a study and work aid. Some individuals build up a tolerance to Ritalin over time.

**ACETYLCHOLINESTERASE INHIBITOR (ARICEPT):** Approved to treat Alzheimer's disease in the 1990s. It has been shown in some studies to enhance memory and attention in healthy individuals.

**MODAFINIL:** Originally used to treat narcolepsy. It can also enhance cognitive function, especially when completing difficult tasks. Experts are not quite sure how it works or what long-term effects would look like.

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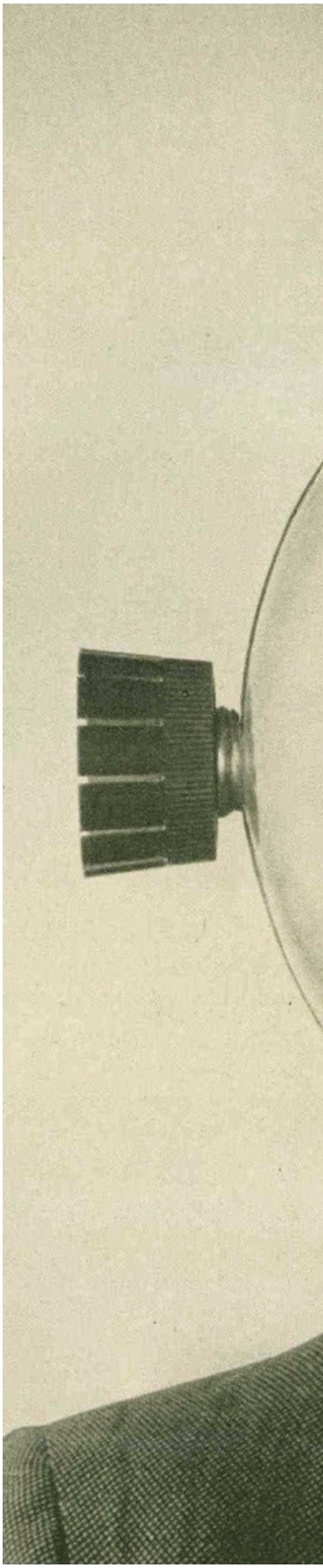
# DO D.I.Y. BRAIN-BOOSTER DEVICES WORK?

Zapping the cranium may juice up neuron circuits, and use is rising—but there might be a cognitive price

*By Esther Landhuis*





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IT BEGAN MORE THAN A DECADE AGO, AS ENGINEERS AND HOBBYISTS STARTED getting enthralled with a jury-rigged electric technology that purportedly enhanced brain function. The movement is still growing, and the brain zappers are no longer just young garage tinkerers—now they include older professionals who fork over hundreds of dollars for high-grade wearable systems. As scientists, clinicians and industry leaders study these fascinating but controversial mind-altering practices, one thing is clear: the idea of applying an electric current to the scalp to boost learning or treat medical conditions in the comfort of one's own home is gaining traction. But does it work?

This form of attempted brain hacking—known as transcranial direct-current stimulation (tDCS)—is not as far-fetched as it might sound. The brain runs on electricity. Brain cells build up charges that impel chemical signals across synapses, the tiny gaps between neurons. When we learn something, the synapses involved become conditioned to fire more readily, and tDCS supposedly enhances that process. The tiny electric currents tDCS uses—generally one to two milliamps—cannot actually trigger the chemical impulse that crosses a synapse, but some researchers believe tDCS strengthens synaptic connections to make learning more efficient. Small laboratory studies suggest it can improve vigilance and reaction times. "You get more bang for your buck" by combining tDCS with conventional training, contends Marom Bikson, a professor of biomedical engineering at the City College of New York.

The dawn of the noninvasive brain-stimulation movement is widely attributed to a 2000 paper by German neurophysiologists Michael Nitsche and Walter Paulus. In a small study of healthy twentysomethings, the scientists showed they could make neurons more or less excitable by sending weak electric currents through the brain's motor cortex. The effects lingered minutes after stimulation. Previously tDCS had only been studied in animals.

A subsequent study in 2003 showed such stimulation could improve a cognitive ability psychologists call motor sequence learning—the process of training the brain in the precisely sequenced steps required to interact with the world via means such as listening or executing a movement. Several labs at Harvard Medical School and the National Institutes of Health picked up on these findings and conducted research suggesting tDCS was promising for stroke rehabilitation and chronic pain.

It was then, in 2006, that Brett Wingeier began watching the field. Trained in medical devices, Wingeier was the principal biomedical engineer at NeuroPace, a Silicon Valley company that manufactures brain implants intended to help control epilepsy. He had also worked on brain stimulators for alleviating cluster headaches and the movement symptoms that afflict patients who have Parkinson's disease. "They can be incapacitated, but you turn the stimulator on, and it all goes away. It's amazing," Wingeier says. Yet he notes that those devices are "only relevant to patients with relatively severe disorders. They're surgical implants."

Wingeier dreamed of using neurotechnology to help more patients—and maybe even healthy people. He was excited to see new tDCS studies, but many were "done with yellow sponges and measuring tape and straps on your head," he says. The time seemed ripe to consider bringing product design principles into what he calls "a legitimate consumer product people can pull out of the box and use."

More plans began taking shape as scientists fleshed out possible mechanisms for how tDCS works. In a set of electrophysiology experiments published in 2009, Bikson and some of his colleagues demonstrated that a mild electric field can synchronize activity in a neural network. Such insights inspired Wingeier and other researchers working to target tDCS to specific brain areas.

Since the 2000 study by Nitsche and Paulus, researchers have published more than 4,000 scientific papers on tDCS—a third of them in the past two years. In the medical realm, some studies suggest brain stimulation might help people with neuropathic pain, as well as depression, schizophrenia and a range of other psychiatric illnesses. For now tDCS remains investigational for medical uses in the U.S., although in Europe such devices are approved for treating pain and depression. More than 800 tDCS studies are listed in the clinicaltrials.gov database that tracks ongoing trials for drug therapies or medical devices. In a small study, tDCS appeared to enhance mood effects in mindfulness meditation, and an ongoing clinical trial is assessing if tDCS can help slow cognitive decline when paired with a computerized training regimen in older adults.

In addition, a growing number of studies are testing tDCS in healthy people and suggest it can improve working memory, attention and decision-making as well as stimulate creativity. A 2012 study funded by the U.S. Department of Defense indicated tDCS may heighten vigilance, making participants twice as fast at spotting bombs, snipers and other threats in fuzzy images. Four other labs have since shown the technology could enhance learning—"one of the few tDCS effects that's been replicated across institutions," says Vincent Clark, a cognitive neuroscientist and first author on the 2012 paper. Clark directs the Psychological Clinical Neuroscience Center at the University of New Mexico.

The tsunami of academic literature on tDCS has spurred a corresponding wave of media articles claiming that jolts to the brain can improve memory, boost math skills and "bring out the genius in you." An article in the *Journal of Medical Ethics* calls tDCS "the Swiss Army knife of human neuroscience." As word of tDCS's potential reaches the general public, home users have been convening in cyberspace. In 2011 tDCS users created a Red-

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dit forum and launched a blog the following year. Thousands of home users visit these Web sites to discuss scientific papers, post how-to videos, and ask questions such as where to place electrodes and how long to stimulate. The Reddit forum has grown from 2,500 to around 11,000 subscribers in the past five years.

In 2013 the first consumer tDCS wearable—a headset for gamers—appeared on the market. Since then, more than a dozen companies have started selling tDCS products. Some offer $40 kits containing wires, electrodes and headbands that the customer assembles at home. At the other end of the spectrum, Halo Neuroscience—the San Francisco–based company Wingeier co-founded in 2013—sells $500 headgear aimed at elite athletes. The device stimulates the motor cortex and promises "gains in strength, explosiveness, endurance and skill" when paired with workouts. Caputron, which launched in 2014, also sells a range of medical-grade consumer brain-stimulation devices. The company distributed more than 10,000 tDCS products in 2015 and more than 20,000 in 2016.

**THE BIOMEDICAL ENGINEER HAD ALSO WORKED ON BRAIN STIMULATORS FOR ALLEVIATING CLUSTER HEADACHES AND THE MOVEMENT SYMPTOMS THAT AFFLICT PARKINSON'S PATIENTS.**

Most consumer tDCS devices are not marketed for clinical purposes but for leisure and cognitive enhancement. None of the consumer kits have officially undergone the rigorous testing process that a drug or medical device must undergo for approval by the Food and Drug Administration, and the purchaser has only the manufacturer's claim that it works for its intended use. And intended uses can be ambiguous. For example, when companies assert their tDCS device "increases concentration" or "amps up brain function," it is hard to determine if such instruments fall under the FDA's purview, says Anna Wexler, now a postdoctoral student at the University of Pennsylvania, who studies the ethical, legal and social implications of neurotechnology. The agency defines a medical device as "an instrument that is … intended to affect the structure or any function of the body," she says. "The way a manufacturer markets the product determines the regulatory pathway," adds Wexler, who explored some of these issues in a 2015 *Journal of Medical Ethics* paper. Enhancement claims have aroused suspicion among scientists, prompting more controlled lab studies. In one experiment, published in March 2016, a team from the Netherlands reported that a commercial tDCS headset actually made participants less accurate in a well-established test of working memory.

Despite uncertainty over efficacy claims, interest in tDCS as a tool for optimizing mental function persists. The devices are small and seem to be relatively safe. Surveying the literature on tDCS human trials, Bikson and his colleagues reported in the fall of 2016 that conventional use has caused no serious adverse effects across more than 33,200 sessions, as well as 1,000 subjects with repeated sessions.

A major problem with assessing how well the technology works is that the vast majority of research studies use brain stimulation for different purposes than do home tDCS users. Contrast home usage with the seminal 2000 paper authored by Nitsche and his colleagues that tested whether noninvasive brain stimulation could help people recover movement after a stroke. "We just wanted to know if we could change motor performance," Nitsche says. "Our question was not, 'Does the stimulation protocol induce maximal performance?'" Home tDCS users, on the other hand, are not particularly interested in making new scientific discoveries, Wexler says. "They're interested in self-improvement."

This quest for enhancement could potentially lead to untoward consequences. In 2016 clinicians and scientists who study tDCS published an *Annals of Neurology* editorial warning of potential undesired effects. For example, stimulating one brain area might help someone learn new material—but hurt the ability to process learned material. Changes in brain activity might last longer than users expect or may extend beyond the regions underneath the electrodes. Also, the effects of tDCS vary tremendously across individuals and with small changes in the process. When it comes to placing electrodes, "even just a few centimeters can be enough to change the effect," Clark says. "How long you stimulate, how much current you put in—if it's two or one milliamp or something in between—all of that matters." Genetics, age and skull thickness also seem to influence response. The technical specifications for medical uses have yet to be clearly delineated, let alone the parameters for cognitive enhancement.

In a New York City conference in the summer of 2017 that Bikson helped to organize, tDCS researchers and vendors met to discuss the technology's potential, as well as concerns surrounding it and other forms of neuromodulation. In 2018 the group published a report to help consumers make informed decisions about purchasing and using these devices. "Right now consumers are a bit confused. They see a $20 device, and they see one that costs $700," Bikson says. "They might not have enough information to appreciate why the $700 device is a higher value for them."

And it looks like tDCS is only the beginning. In addition to applying direct current to the scalp, brain-hacking researchers and D.I.Y.ers are experimenting with other methods, including alternating-current and random-noise stimulation. These might one day complement more established noninvasive medical technologies, such as magnetic stimulation and ultrasound, to influence brain function and behavior. Transcranial direct-current stimulation, Clark says, "is just the tip of the iceberg." SA

**Esther Landhuis** is a freelance science journalist in the San Francisco Bay Area.

MORE TO EXPLORE

**A Pragmatic Analysis of the Regulation of Consumer Transcranial Direct Current Stimulation (TDCS) Devices in the United States.** Anna Wexler in *Journal of Law and the Biosciences,* Vol. 2, No. 3, pages 669–696; November 2015.

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# The Remarkable Reach of Growth Mindsets

## Believing in people's ability to change can help thwart teen depression, spur workplace creativity and ease political conflict

*By Carol S. Dweck*

*Illustrations by Ellen Weinstein*



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DO YOU THINK IT IS POSSIBLE TO INCREASE YOUR INTELLECTUAL ABILITY? FOR DECADES I have studied the power of this belief—a belief that intellectual abilities can be developed—to become reality, and I have watched as the concept of maintaining a "growth mindset" has taken root in education and parenting circles. My colleagues and I have now shown repeatedly that students who believe their intelligence can grow tend to learn more, acquire deeper knowledge and do better—especially in hard subjects and in negotiating difficult school transitions—compared with equally able students who believe their intelligence is a fixed trait.

The reason is simple: students with a growth mindset are not as worried about looking intelligent, and so they take on more challenges, persist longer and are more resilient in the face of setbacks. In contrast, those with a "fixed mindset" tend to see challenges as risky and effort and setbacks as signs of limited talent.

Newer research is revealing just how potent this effect can be. Consider one example: In 2014 my Stanford University colleagues Susana Claro and Dave Paunesku and I analyzed census data, examination results and mindset beliefs from 147,000 10th graders in Chile. We found that at every level of family income, the students who favored a growth mindset—as measured by a questionnaire we developed—enjoyed substantially higher levels of academic achievement than those who espoused a fixed mindset. In fact, poorer kids with growth mindsets often performed as well as far more privileged kids with fixed mindsets.

We are also discovering more about how fixed mindsets are passed on—often inadvertently and with the best of intentions—by parents, teachers and peers. Fortunately, those attitudes can be reset toward growth. Through in-person workshops and online modules, we have successfully taught thousands of students—from middle school to university—that when they step out of their comfort zone to learn hard, new things, the neurons in their brain form new or stronger connections, boosting their abilities over time. They learn how to apply this idea to their schoolwork and how it has helped others to succeed.

In recent years a growing body of research has further demonstrated that, well beyond the classroom, a growth mindset can help thwart depression, decrease aggression, strengthen willpower, predict creativity in the workplace and possibly advance conflict resolution among long-standing enemies. It seems incredible (even to us!), so I would like to tell you more about these exciting new lines of work.

## WEATHERING ADOLESCENT ANGST

DURING THE PAST FEW YEARS we have come to appreciate that mindsets can shape not just academic but also social success at school. In particular, we have focused on teenagers, who often feel harshly judged by their peers and may wonder, "Am I a 'mis-

IN BRIEF

**A growth mindset**—or the idea that you can grow your abilities through hard work, good strategies, and input from others—yields benefits beyond the classroom for teens, adults, businesses, even political adversaries. **Identifying how teachers,** parents, bosses and peers communicate mindsets may increase the number of people who benefit from growth mindset beliefs. **Parents and teachers** who think they hold a growth mindset still sometimes convey fixed mindset messages—especially when they express the view that setbacks are detrimental to a child's learning.



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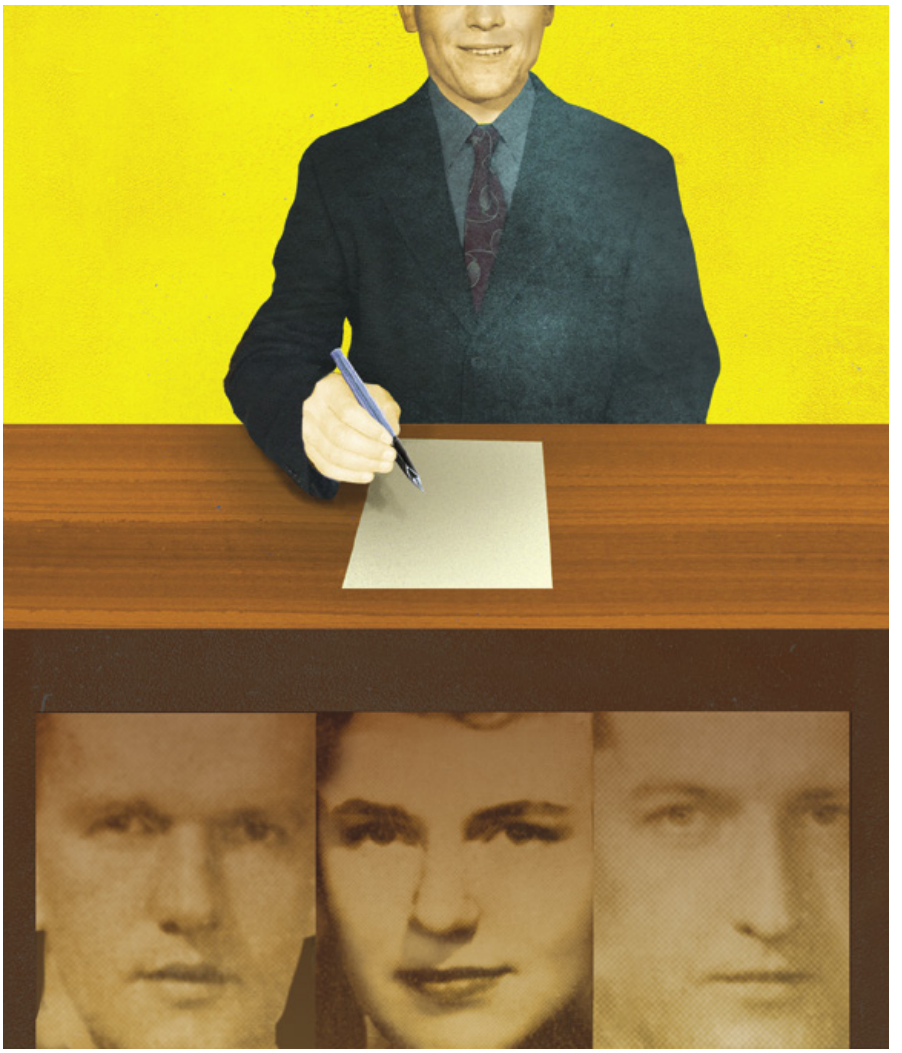
fit'? And will I always be this way?" Developmental psychologist David Yeager, now at the University of Texas at Austin, and I theorized that teens who see themselves and others as evolving, growing people might be better positioned to deal with these social stresses, whereas those with more fixed mindsets might harbor more hostile feelings toward peers who exclude them because those peers have made them feel like permanent "losers."



To test this idea, we launched a series of studies in 2011. First we measured adolescents' mindsets about personality—that is, whether they saw personal qualities as fixed or subject to ongoing development. Then we asked them to report on their social conflicts with peers. We found that when adolescents in a fixed mindset experienced or recalled exclusion or rejection by their peers, they harbored more shame, hatred and fantasies of violent revenge. This pattern was true regardless of the students' socioeconomic backgrounds.

Next Yeager designed a workshop to teach a growth mindset about personality. More than 200 ninth and 10th graders in a large, low-income high school near San Francisco participated. Over the course of six sessions, they learned that all people have the potential to grow and change—it is not easy but is always possible. Although the staff of the school warned us that it was too late for these teens to change their behavior ("Go help younger kids," they said), the impact of the workshop was clear.

Compared with control groups, who received no training or different training, the students who attended the six growth mindset sessions showed reduced aggression in school, as reported by their teachers, who did not know which training the students had received. One month later Yeager put all the kids in the study into a trying situation—specifically, they were temporarily excluded by peers while playing a computer-based ball-tossing game. The growth mindset group responded less aggressively and more compassionately than control subjects toward the kids who left them out, even when they were given the opportunity to retaliate.

Yeager and his collaborator Adriana Miu, now in the psychiatry department at Stanford, went on to examine the role these mindsets play in adolescent depression, known to increase markedly in the first year of high school. In a 2014 study with 599 students, they found that teaching a growth mindset about personality at the start of ninth grade could reduce the incidence of serious depressive symptoms by nearly 40 percent, compared with the results for a control group who received different instruction. In fact, in this study, Miu and Yeager largely prevented the typical spike in new cases of depression among high school freshmen.

The social effects of mindset apply to adults as well as teens. Thinking of ourselves as capable of growth can help us weather difficult periods full of judgments and setbacks. And if we can see our adversaries as capable of growth, we can interact more successfully with them. One of our most ambitious projects to date brought together several U.S. psychologists with Eran Halperin of the Interdisciplinary Center Herzliya in Israel to consider the influence of mindsets on participants caught up in Middle East conflict. We showed that when Jewish Israelis or Palestinians are led to adopt a growth mindset about social groups—learning that groups can change and do not have an inherent, immutable nature—they can come to view one another less negatively and become more willing to entertain serious compromises for the sake of peace.

In research that we carried out with Halperin, together with my Stanford colleagues James Gross and Amit Goldenberg, we found that these attitude shifts can endure. Six months after a growth mindset workshop, many of the people who had learned a



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## Getting the Message Right for Kids

Many of us declare that we have a growth mindset, when in fact, we all hold a mixture of fixed and growth mindsets. For many, a fixed mindset arises when we contemplate stepping out of our comfort zone or when we face criticism or setbacks. In these cases, does a voice in your head say, "You might not have the ability, and everyone will know it" or "Go for it. Learn. Struggle is part of learning. Ask for input or mentoring"?

Many parents and educators incorrectly believe they are fostering the latter attitude when they exhort children to try hard. Some educators even blame kids who do not comply: "I can't teach this child. He has a fixed mindset." But simply urging children to try hard is not enough. It does not teach them how the brain grows through learning or how hard work and new strategies lead to deeper learning. And it does not dispel the fixed mindset belief that hard work is for people who are not that smart to begin with. Never mind that children of all ages experience the generic call to hard work as nagging—something that adults are very good at doing and that kids are very good at ignoring.

Also in the name of a growth mindset, some adults blithely assure children that they can do anything if only they work hard enough. But if a child lacks the necessary skills, strategies, support or mentoring, such reassurance is hollow and even misguided. On the flip side, some parents and educators have taken to lavishly praising effort, even when a child has not in fact worked hard or effectively. This tactic, too, sends a discouraging message: "You are not capable of anything better."

To convey a true growth mindset, adults must help kids understand what they need to do to develop their abilities and to guide them in that process. We see a "process focus" as appreciating not only children's genuine efforts but also their use of good strategies and their appropriate seeking of input from others as they strive to meet a high standard. We also see a process focus as tying these strategies directly to the child's learning and progress. What about when a child has tried hard but fallen short? The adult can appreciate the effort but point to the next step: "Let's talk about what strategies you've tried and what you can try next."

*—C.S.D.*

growth mindset perspective remained more optimistic than those in a control group about the possibility of forging a better future.

### ENABLING GROWTH ON THE JOB

ANOTHER GROWING REALIZATION in my field is that mindsets can characterize and drive large, organized groups just as they influence individuals. Starting in 2010, Mary Murphy, now at Indiana University Bloomington, and I began collaborating with researchers at several other institutions to examine the role of mindsets at a group of Fortune 1000 companies. We asked hundreds of employees from seven of these businesses to complete a questionnaire: Did their company believe in fixed talent, or did it instead believe in the development of employees' abilities? Notably, there was good consensus among workers on whether their company had a growth or fixed mindset.

We learned that mindsets made a big difference in terms of employee attitudes and job satisfaction. The people who worked for growth mindset businesses said they felt far more empowered by their company and committed to it. They said that their organization valued innovation and creativity—much more so than those who worked for fixed mindset companies—and that it would support them if they took a reasonable risk that did not work out. In contrast, those in fixed mindset companies reported that fellow employees engage in more devious practices—keeping secrets, hoarding information—all designed to make them look like winners in the talent hierarchy.

Perhaps most revealing, we found that the managers in growth mindset companies more frequently said that their employees showed the potential to rise and become stars, compared with managers in fixed mindset companies. I find that ironic because the fixed mindset companies, for all their emphasis on talent, were, down the road, not seeing as much potential in their workers.

### COUNTERING BIAS

JUST AS CORPORATIONS can embrace distinct mindsets, so can entire academic fields. In 2015 philosophy professor Sarah-Jane Leslie of Princeton University, psychologist Andrei Cimpian, now at New York University, and others uncovered how these mindsets influence who is thought to excel in certain disciplines. They polled scholars working in 30 different areas and asked them the extent to which success in their field required inherent talent (a fixed mindset) versus dedication, discipline and hard work (more consistent with a growth mindset). Two strong correlations emerged: the more a field valued inborn genius, the fewer women and the fewer African-Americans earned Ph.D.s in that subject [see "The Brilliance Trap," by Andrei Cimpian and Sarah-Jane Leslie, on page 106]. This relation held true not just for math and science fields, such as physics and chemistry, but also for the humanities and social sciences, including economics and philosophy.

Through further questioning, this research team discovered that disciplines that buy into the idea of inherent genius tend to be both less attractive and less welcoming to women. In a wonderful, complementary line of research, Murphy and her colleagues are demonstrating, in an ongoing study with college students, that when women view their science instructors as believing in fixed, inherent talent, they feel less confident that they belong in science. In other words, they view the professor as believing that only some students have what it takes—and they tend to suspect that as women, they do not fall into that category. Murphy is seeking to identify precisely the kinds of statements and practices through which science instructors convey these fixed mindset messages, with the goal of developing and testing a program to help educators create growth mindset cultures in their classrooms.

These findings are key to understanding the gender, racial and ethnic gaps in important fields. They suggest that we need to



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pay close attention to the mindset messages we send students. In doing so, we may begin to find ways to increase the number of women and minorities who enter math, science and economics—disciplines that support an increasing number of vital jobs in our society.

## PARENTING AND PRAISE

SO HOW ARE MESSAGES about mindset relayed within families, schools and organizations? Our past research has shown that when adults praise a child's intelligence or talent, it sends a fixed mindset message, with all its associated liabilities. Children hearing this praise may no longer want to challenge themselves and are discouraged by difficulty, which, in this framework, suggests to them that they might not be so smart after all. But children whose parents and teachers offer what I describe as "process praise"—linking their success to hard work or good strategies—tend to adopt more of a growth mindset, embrace struggles and thrive in the face of challenge.

Now, you might think that parents and teachers who have growth mindsets themselves would naturally transmit them to the children in their care. In that case, we could just teach a growth mindset to the adults and sit back. But as we and other researchers are now discovering, overt words and deeds speak louder than covert mindsets—and the two do not always match. Let us look more closely.

In 2013, together with colleagues at Stanford and the University of Chicago, I examined how mothers praise their babies, analyzing videotaped interactions when the tots were one, two and three years old. Five years later, when the children were in second grade, we assessed their mindset and appetite for challenge. At that point, we also asked the mothers about their mindset and whether they believed that intelligence and other personal qualities were traits that were fixed or that could be developed.

We discovered that the mothers' earlier pattern of praise predicted their children's mindset and desire for challenge in second grade, but the mothers' own reported mindset did not. Mothers who said they had a growth mindset but did not praise the process their children engaged in did not tend to raise kids who welcomed challenge or believed in growth as much. But consistent with our past research, the mothers who gave their children more process praise—focused on actions, persistence or strategies—relative to other forms of praise raised kids with stronger growth mindsets and more interest in tackling challenges. In a follow-up study, we have just found that this latter group of children continued to progress and showed higher math and verbal achievement two years later, in fourth grade.

Thus, many mothers who believe in a growth mindset may not know how to put it into practice [*see box on opposite page*].

Research by Kyla Haimovitz, formerly a Ph.D. student in my lab at Stanford, and me continues this story. We were looking at parents' views of failure and their reactions to their children's setbacks. In a series of studies, we found that parents who believe setbacks are harmful (as opposed to helpful) to a child's learning tend to foster a fixed mindset in their offspring. When they react to their kids' setbacks with anxiety or concern, the children are led to believe that setbacks reflect badly on their (permanent) ability. Here, too, many parents espoused a growth mindset, but if they did not translate that into a positive reaction to errors, they passed on more of a fixed mindset to their kids.

More recent research, this time looking at middle school math teachers, tells the same tale. In her fascinating dissertation research at Stanford, Kathy Liu Sun found that many of the math teachers she surveyed said they embraced a growth mindset and even used the words "growth mindset" in their classrooms. If, however, they did not back that up with growth-focused teaching methods—for example, emphasizing an understanding of the underlying concepts, giving feedback to deepen that understanding, and offering students a chance to revise and resubmit their work to demonstrate their enhanced understanding—their students tended to cling to a fixed mindset in math. The students did not fully benefit from the experience of growing their mathematical abilities.

Taken together, these results have inspired us to look even more deeply into the practices—the words and deeds—that convey to children and adults that their talents can be developed. Through research, we are seeking to identify more of these practices and to spell them out clearly so that those who hold a growth mindset and wish to foster it in others can pass it on effectively. But as we scientists are so fond of saying, more research is needed. Please stay tuned. SA

**Carol S. Dweck** is Lewis and Virginia Eaton Professor of Psychology at Stanford University and author of *Mindset: The New Psychology of Success*.

### MORE TO EXPLORE

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**Parent Praise to 1- to 3-Year-Olds Predicts Children's Motivational Frameworks 5 Years Later.** Elizabeth A. Gunderson et al. in *Child Development*, Vol. 84, No. 5, pages 1526–1541; September/October 2013.
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# FIT BODY, FIT MIND?

How can you stay sharp into old age? It is not just a matter of winning the genetic lottery. What you do can make a difference

*By Christopher Hertzog, Arthur F. Kramer, Robert S. Wilson and Ulman Lindenberger*

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As everybody knows, if you do not work out, your muscles get flaccid. What most people don't realize, however, is that your brain also stays in better shape when you exercise. And not just challenging your noggin by, for example, learning a new language, doing difficult crosswords or taking on other intellectually stimulating tasks. As researchers are finding, *physical* exercise is critical to vigorous mental health, too.

Surprised? Although the idea of exercising cognitive machinery by performing mentally demanding activities—popularly termed the "use it or lose it" hypothesis—is better known, a review of dozens of studies shows that maintaining a mental edge requires more than that. Other things you do—including participating in activities that make you think, getting regular exercise, staying socially engaged and even having a positive attitude—have a meaningful influence on how effective your cognitive functioning will be in old age.

Further, the older brain is more plastic than is commonly known. At one time, the accepted stereotype was that "old dogs can't learn new tricks." Science has proved that this dictum must be discarded. Although older adults generally learn new pursuits more slowly than younger people do and cannot reach the peaks of expertise in a given field that they might have achieved if they had started in their youth, they nonetheless can improve their cognitive performance through effort—forestalling some of the declines in cognition that come with advancing age. As John Adams, one of the founding fathers and the second U.S. president, put it: "Old minds are like old horses; you must exercise them if you wish to keep them in working order."

The news comes at a propitious time. The proportion of older adults in the U.S. and in other industrial nations continues to grow: in 1900, 4.1 percent of U.S. citizens were older than 65; by 2000, that amount had jumped to 12.6 percent. By 2030, 20 percent of us will be in that category. From a societal point of view, prolonging independent functioning is both a desirable goal in itself and a way of deferring costs of long-term care. For individuals, maintaining optimal cognitive functioning is worthwhile simply because it promises

IN BRIEF

**We are used to thinking** of intelligence as largely a matter of genetic inheritance, but that is not the whole picture. What we do affects our mental well-being: staying physically and mentally active helps us stay sharp as we age.

**Nevertheless, our personal efforts** to bolster cognitive enhancement cannot forestall all declines in our cognitive performance.

**What is especially surprising** is the powerful link between physical activity and mental acuity. Staying fit helps us keep cognition more robust as well. Older adults who participate in aerobic exercise outperform their peers who do not.



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**KEEPING MUSCLES** in shape also benefits cognition.



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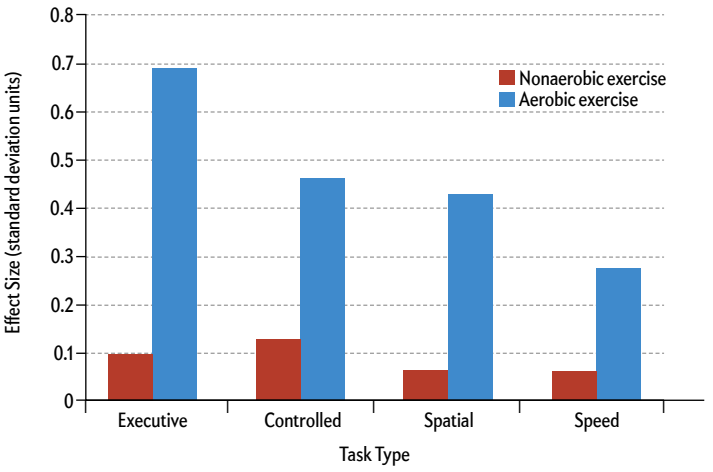
## The Power of Walking

**Older adults** who participated in aerobic exercise (walking) outperformed those in programs for stretching and toning (controls) in cognitive task areas: executive (related to planning and multitasking), controlled (effortful processes in response to novel situations), spatial (dealing with spatial information in perception or memory) and speed.




to enhance our quality of life through the years.

### MENTAL TRAINING

HOW TO KEEP MINDS keen over an entire life span is a question philosophers have mulled since the earliest writings on record. As Roman orator Cicero put it: "It is exercise alone that supports the spirits, and keeps the mind in vigor." Modern research in this field began in the 1970s and 1980s, with studies that demonstrated that healthy older adults can improve performance to a greater extent than had been previously assumed. The earlier research did not fully address certain questions, such as how long adults could retain the new skills they had acquired through training, whether those specifically developed skills would also positively influence other areas of cognition needed in everyday life, and whether the studies done with small numbers of subjects would be broadly applicable.

Cognitive training can lead to substantial benefits for older adults on the tasks trained, and some of these benefits are maintained over time and may transfer to other tasks. Toward the end of the 20th century the National Institute on Aging funded a consortium of researchers to conduct a large-scale training study in a sample of older Americans. In 2002 psychologist Karlene Ball of the University of Alabama at Birmingham and her colleagues published initial results on more than 2,500 individuals older than 65 who had received about 10 sessions of cognitive training. Participants were randomly assigned either to a cognitive-process training group to learn how to excel in one of three areas—memory, reasoning or visual search—or to a control group of subjects who did not receive training. At a follow-up two years later, the team randomly selected a set of the initial participants for booster training prior to evaluation. The results showed strong training-effect sizes in each group as compared with controls. In retests five years later, measurable training benefits were still present.

More impressive, however, are recent training studies that focus on what psychologists call working memory and executive functions—how a person plans a strategic approach to a task, controls what is attended to, and how he or she manages the mind in the process. Psychologist Chandramallika Basak, then at the University of Illinois, and her colleagues showed that training in a real-time strategy video game that demands planning and executive control not only improved gaming performance but also enhanced performance on other tasks measuring aspects of executive control.

Some studies have also increased the amount of practice provided. For instance, Florian Schmiedek and one of us (Lindenberger) of the Max Planck Institute for Human Development in Berlin and Martin Lövdén of the Karolinska Institute in Stockholm asked 101 younger and 103 older adults to practice 12 different tasks for 100 days. Each of the tasks belonged to one of three different sets of cognitive skills—working memory, episodic memory and perceptual speed. Both younger and older adults showed general improvements in working memory. Younger adults also broadly improved in memory and reasoning and maintained their gains in reasoning over a period of two years.

You do not have to have specialized training, however, to achieve cognitive gains or ward off cognitive decline. Everyday activities such as reading can help. We reviewed evidence on activity-related cognitive enrichment in more than a dozen studies. In 2003 one of us (Wilson) and his colleagues at Rush University Medical Center in Chicago recruited more than 4,000 elderly residents from a geographically defined community and rated their frequency of participation in seven cognitive activities (for instance, reading magazines). At three-year intervals for a mean of nearly six years, participants completed an in-home interview that included brief tests of cognitive function. More frequent cognitive activity at the outset was associated with a reduced rate of cognitive decline over time. But not all studies of staying cognitively active have found such benefits.

SOURCE: "FITNESS EFFECTS ON THE COGNITIVE FUNCTION OF OLDER ADULTS: A META-ANALYTIC STUDY," BY STANLEY J. COLCOMBE AND ARTHUR F. KRAMER. IN *PSYCHOLOGICAL SCIENCE*, VOL. 14, NO. 2; MARCH 2003



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## GETTING PHYSICAL

OVER THE PAST DECADES several studies have underscored the link between physical activity and cognition. For instance, in a study published in 2001 neuropsychiatrist Kristine Yaffe of the University of California, San Francisco, and her colleagues recruited 5,925 women older than 65 at four different medical centers across the U.S. The participants were all free of any physical disability that would limit their ability to walk or pursue other physical activities. The volunteers were also screened to ensure that they did not have a cognitive impairment. The researchers then assessed their physical activity by asking the women how many city blocks they walked and how many flights of stairs they climbed daily and gave them a questionnaire to fill out about their levels of participation in 33 different physical activities.

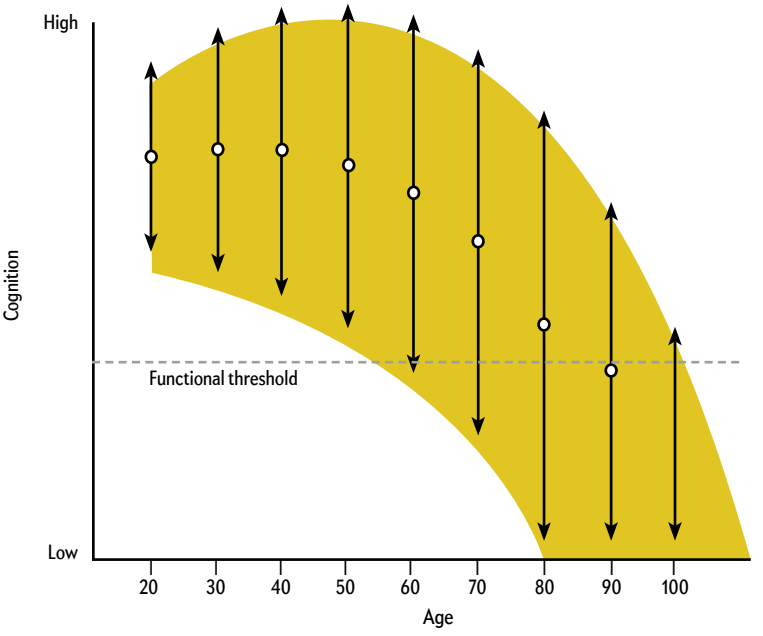
After six to eight years, the researchers assessed the women's level of cognitive function. The most active women had a 30 percent lower risk of cognitive decline. Interestingly, walking distance was related to cognition, but walking speed was not. It seems that even moderate levels of physical activity can serve to limit declines in cognition.

Moderate movement is good, but toning your circulatory system with aerobic exercise may be the real key to brain fitness. In a 1995 study of 1,192 healthy 70- to 79-year-olds, cognitive neuroscientist Marilyn Albert of Johns Hopkins University and her colleagues measured cognition with a battery of tasks that took approximately 30 minutes to complete and included tests of language, verbal memory, nonverbal memory, conceptualization and visuospatial ability. They found that the best predictors of cognitive change over a two-year period included strenuous activity and peak pulmonary expiratory flow rate.

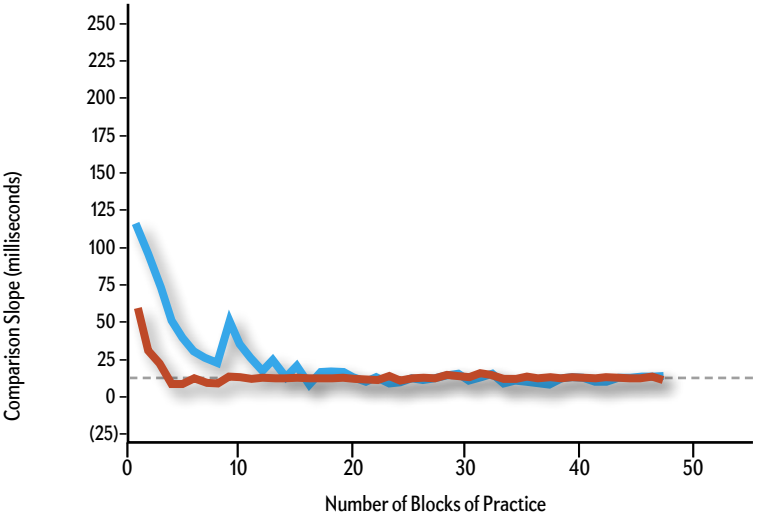
In an investigation published in 2004 epidemiologist Jennifer Weuve, then at Harvard University, and her colleagues also examined the relation between physical activity and cognitive change over a two-

# Capabilities over Time

**An individual's cognitive function** can vary from maturity into old age. Although good habits can promote sound thinking within a given range (*1*), we cannot completely halt the effects of aging (*2*).




1 Everyone experiences cognitive decline over a lifetime, but exercising the mind and body can help individuals stay above the middle (*white dots*) of the cognitive range (*shaded area*) and remain functional even beyond age 90.




2 In one study of practice benefits, older adults (mean age 72, *blue*) were slower than younger adults (mean age 21, *red*) to search memory (comparison slope, *vertical axis*) to verify whether a word was one of a set they had committed to memory a short time earlier. But with enough practice, they could speedily identify target words without needing to search for them, producing zero slopes such as those produced by younger people.

SOURCE FOR GRAPH 1: "ENRICHMENT EFFECTS ON ADULT COGNITIVE DEVELOPMENT: CAN THE FUNCTIONAL CAPACITY OF OLDER ADULTS BE PRESERVED AND ENHANCED?" BY C. HERTZOG ET AL., IN *PSYCHOLOGICAL SCIENCE IN THE PUBLIC INTEREST*, VOL. 9, NO. 1; OCTOBER 2008. © 2009 ASSOCIATION FOR PSYCHOLOGICAL SCIENCE. SOURCE FOR GRAPH 2: "AGING AND INDIVIDUAL DIFFERENCES IN THE DEVELOPMENT OF SKILLED MEMORY SEARCH PERFORMANCE." BY C. HERTZOG ET AL., IN *PSYCHOLOGY AND AGING*, VOL. 11, NO. 3; 1996



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year period in 16,466 nurses who were older than 70. Participants logged how much time they spent per week in a variety of physical activities (running, jogging, walking, hiking, racket sports, swimming, bicycling, aerobic dance) over the past year and provided self-reports of walking pace in minutes per mile. Weuve's group observed a significant relation between energy expended in physical activities and cognition, across a large set of cognitive measures.

The research that we have described thus far has examined mental performance over relatively short periods—just several years. A few studies have begun to look at what happens over longer timescales. In 2005 Suvi Rovio, now at the University of Turku in Finland, and her colleagues examined the relation between physical activity at middle age and risk of dementia an average of 21 years later, when the cohort was between 65 and 79 years of age. Subjects indicated how often they participated in leisure-time physical activities that lasted at least 20 to 30 minutes and caused breathlessness and sweating. Conducting such activity at midlife at least twice a week was associated with a reduced risk of dementia in later life. Indeed, participants in the more active group had 52 percent lower odds of having dementia than the more sedentary group did.

In 2010 Kirk Erickson and his colleagues at the University of Pittsburgh extended previous research examining the relation between physical activity, cognition and dementia by assessing self-reported physical activity alongside measures of regional brain volume. They reported an association between walking and retention of brain volume, which in turn predicted a reduced risk of dementia in 299 older adults over a period of 13 years. Interestingly, it is not just aerobic forms of physical activity (such as walking, jogging, swimming and bicycling) that have been associated with improvements in cognition. Teresa Liu-Ambrose, a professor of physical therapy at the University of British Columbia, reported in 2010 that resistance exercise, over a one-year period, improved aspects of executive control in older women.

CORBIS

## MIND-BODY CONNECTION

IT MAKES SENSE that training or participation in mentally stimulating activities would help cognition, but it is perhaps less immediately obvious why physical activity would have such an effect. Consider the increasingly well-documented link between physical activity and disease. A plethora of studies have examined the health benefits of exercise and a nonsedentary lifestyle for prevention of disease. For example, we now know that physical activity reduces the risk of cardiovascular-related death, type 2 diabetes, colon and breast cancer, and osteoporosis. On the other hand, cardiovascular disease, diabetes and cancer have been associated with compromised cognition. Therefore, you might expect that increased physical activity and exercise would maintain cognition by reducing risk of diseases associated with cognitive decline.

In a study published in 2006 psychologist Stanley J. Colcombe, then at the University of Illinois, and his colleagues examined the influence of fitness training on potential changes in brain structure. The six-month trial included 59 healthy but sedentary community-dwell-



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ing volunteers, age 60 to 79. Brain scans after fitness training showed that even relatively short exercise interventions can begin to restore some of the losses in brain volume associated with normal aging. In 2011 Erickson and his colleagues reported on work done at the University of Illinois, which showed that one year of walking, an hour a day for three days a week, increased the volume of the hippocampus in older adults. The hippocampus supports important aspects of memory such as associating an individual's face with her name and discussions that you might have had with her.

Researchers have found that different brain regions that need to communicate to support memory, reasoning and problem-solving become more poorly connected as we age. A study by Michelle Voss of the University of Illinois and her colleagues found, however, that when older adults participated in a six-month walking program, connections increased in a number of brain networks, and this increased connectivity was associated with improvements in executive-control processes (such as scheduling, planning, dealing with ambiguity, and working memory). Other recent studies have replicated and extended these results. These studies and those presented earlier in the article suggest improvement in cognition, brain structure and function in response to improvement in fitness.

Supporting these findings, a large body of nonhuman animal research has demonstrated a number of changes in brain structure and function after animals are exposed to enriched, or complex, environments. Enriched environments usually include running wheels, a multitude of toys and objects to climb that are changed frequently, and animal companions. Exposure to such environments yields several physiological benefits. First, it increases the formation of new dendrite branches and synapses—the areas of neural cells that receive

**PHYSICAL ACTIVITY bolsters memory and thwarts dementia.**



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**WORKING ON PUZZLES** can help maintain mental acuity.



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and send communication signals. It also increases the number of glial cells, which support the health of neurons, and expands the brain's oxygen-supplying capillary network. Enriched environments foster the development of new neurons and create a cascade of molecular and neurochemical changes, such as an increase in neurotrophins—molecules that protect and grow the brain. Finally, physical activity in animals results in improvements in learning and memory.

Doing puzzles and push-ups are helpful for some—but other factors also boost mental fitness. For one, getting involved in social groups both improves cognition in general and seems to help thwart the arrival of dementia. The traditional focus of this research has been on relatively objective measures of social isolation versus connectedness, including the extent to which a person participates in activities that prominently involve social interaction (such as doing volunteer work), the number of friends and relatives an individual contacts regularly (in other words, the size of a person's social network), and marital status. Findings about the positive aspects of attitudes and beliefs on adult cognition are spottier. In large part, positive beliefs and attitudes may have important indirect effects on cognitive enrichment because of their influence on the kinds of behaviors (for instance, exercise and mentally stimulating activities) that are known to be associated with cognitive enrichment.

More generally, individuals who are optimistic, agreeable, open to new experiences, conscientious, positively motivated and goal-directed are more likely to undergo successful aging, to take advantage of opportunities, to cope effectively with life circumstances, to effectively regulate emotional reactions to events, and to maintain a sense of well-being and life satisfaction in the face of challenge.

And just as maintaining some activity patterns in old age may reduce risk of cognitive decline, the persistence of other patterns of behavior may increase the risk. Chronic psychological distress—resulting from depression, anxiety, and negative emotions such as anger and shame—is associated with a variety of negative outcomes in adulthood, including cognitive decline. The tendency to experience psychological distress is often called neuroticism. Studies have consistently found a higher level of neuroticism to be linked to an increased incidence of Alzheimer's disease and mild cognitive impairment in old age.

## ENRICHING COGNITION

CLEARLY, THERE IS NO MAGIC PILL that inoculates the individual against cognitive decline in old age. Thus, public policy should follow a health prevention model. Policy leaders might promote intellectual activities that are inherently meaningful for older adults, perhaps as embedded in larger social contexts (for example, the Elderhostel movement or adult continuing education). A critical issue for future research will be to understand how an engaged way of life can be promoted and implemented in midlife, during the working years. Given inevitable conflicts between work demands and time available for other roles (parenting, for one) and activities, it would be useful to know whether work-related activity programs (such as availability and use of physical exercise facilities at or near the workplace) could help foster an enriching lifestyle.

At the same time, the public must be aware that there is still much that is not known about cognitive fitness in old age, as well as some controversy about the magnitude and durability of mental exercise outcomes. People are marketing computer games and other means of exercising the mind, often making strong claims about the effectiveness of expensive products that have not been backed by actual scientific studies. Consumers should look for evidence demonstrating the benefits of such products—particularly with regard to everyday activities such as driving, memory for daily activities and better financial decision-making.

The next decades offer much promise for expanding our knowledge about aging and cognition. We may soon discover whether the limits on successful cognitive functioning in old age that were once seen as insurmountable can ultimately be viewed as pessimistic assumptions that focused on observable age-related decline rather than the potential for maximizing human performance through cognitive enrichment. Just as advances in medical science may lead to increased longevity through vehicles such as effective treatments for dementia-causing illnesses, advances in psychological science can make important contributions to improving the quality of life of long-living older adults. In part, these advances will empirically demonstrate that attitudes and behaviors can promote cognitive functioning in old age and, more generally, show how behavioral interventions can help us all age successfully. SA

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**Arthur F. Kramer** is a professor of psychology and neuroscience and director of the Beckman Institute for Advanced Science and Technology at the University of Illinois.

**Robert S. Wilson** is a professor of behavioral and neurological sciences at Rush University Medical Center in Chicago.

**Ulman Lindenberger** is director of the Center for Lifespan Psychology at the Max Planck Institute for Human Development in Berlin.

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# The Aha! Moment

## A step-by-step guide to your next creative breakthrough

*By Nessa Bryce*

*Illustrations by Colin Hayes*



*Painting by Nessa Bryce*

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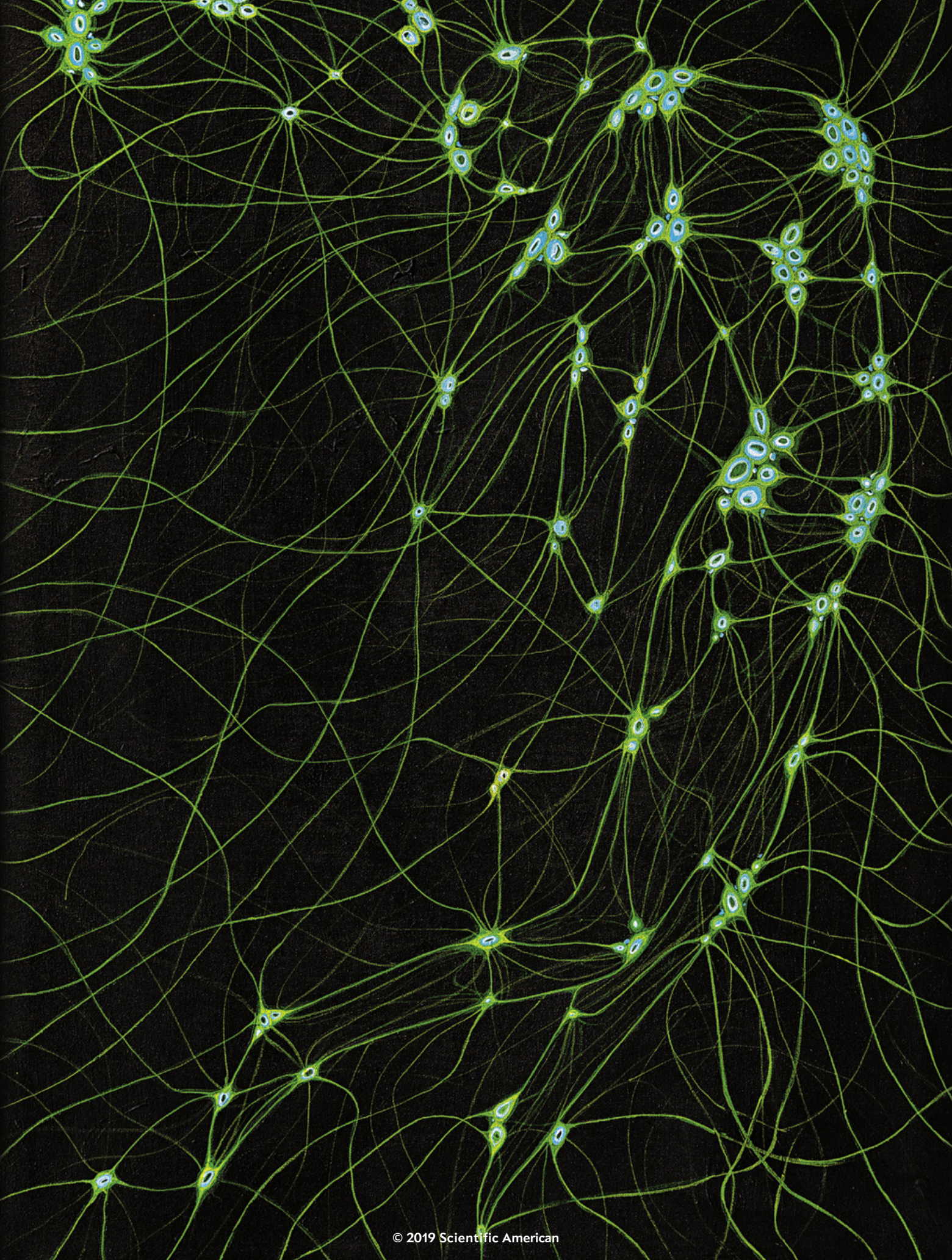

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TAKE A MOMENT TO LOOK AT THE IMAGE ON THE PRECEDING page. What do you see? Just a neural network? Perhaps you spotted the hidden figure. If so, you have just had a moment of insight. You may have felt a similar jolt when discovering the solution to a math problem, understanding a joke or metaphor, or realizing something unexpected about yourself. These aha! moments occur when your brain spontaneously reinterprets information to reach a novel, nonobvious conclusion.

I painted *Neurons* a few years ago for an art exhibit. I had designed the piece to portray the idea that our brain's neural networks make us who we are. It was only after joining psychologist James T. Enns's vision laboratory at the University of British Columbia in 2013 that I had my own abrupt realization: I recognized how my art could inform science. Using this piece, along with other hidden-object images, I investigated how an individual's focus and attention change when experiencing an unexpected revelation.

For centuries creative individuals have described their sudden breakthroughs, instances when they are able to recombine information in a new and useful way. Scientists view these flashes of insight as markers of the creative process—and observing them in the laboratory elucidates what happens in the brain during problem-solving.

"A story is emerging about all the factors that lead up to an insight," says cognitive psychologist John Kounios, who studies creativity at Drexel University.

What researchers are finding is that the contemporary science of creativity largely bolsters an almost century-old theory. In 1926 political scientist Graham Wallas defined the creative process as four distinct stages: preparation, incubation, illumination and verification. Since then, scientists have broken some of his stages into substages to reveal distinct cognitive processes. For example, preparation now consists of two parts, one involving general learning and the other more focused on skill building.

These stages really seem to be universal, whether you are a scientist, artist, writer or musician," says Harvard University psychologist Shelley Carson, who has interviewed more than 1,000 creative individuals for her research. And creativity is not restricted to a subset of highly talented artists and thinkers, Carson says. These innovative individuals have a distinct style of thinking, and breaking down their approach can allow anyone to re-create the process. Brain research has revealed that we can all get closer to achieving that magical spark of insight with the help of a few simple techniques.

IN BRIEF

**Psychologists** study the moment of insight, or the abrupt realization of a new solution, as a marker of the creative process.

**Researchers** have broken down the discovery of insightful solutions into stages, including preparation, incubation, illumination and verification.

**Recognizing** the distinct cognitive processes underlying each stage can help everyone use an insightful approach to find innovative solutions.



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## STAGE 1 : EXPLORE

Roughly speaking, people solve problems in one of two ways: they either tend to rely on moments of insight, or they prefer to approach them analytically. Answering questions with analysis involves finding solutions through deliberate, methodical trial and error, whereas insight is perceived as an abrupt epiphany. Both methods are useful, but insight is typically seen as the best option for "out of the box" solutions.

In 2008 Kounios and his colleagues monitored the brain activity of 26 study participants using electroencephalography (EEG) while they sat quietly in a room. After recording these electrical signals, the researchers asked the participants to try to solve 180 anagram problems, which involved reorganizing a word, such as "west," to form another word, "stew." Subjects also reported whether they had used an insightful or analytical approach to solve each problem.

Kounios found that the brain activity of people who used insight differed significantly from that of people who preferred the analytical approach. Before they even began solving problems, most members of the insight group exhibited less activity in the occipital lobe, a region involved in visual processing, compared with the analytical set.

Specifically, the brains in the insight group showed less activity in the so-called alpha-wave range, which reflects neural inhibition, and the beta-1-wave range, which is linked with selective visual attention. In other words, these findings suggest that people who rely on insight tend to experience diffuse visual attention when not actively engaged in a task.

This study, along with Carson's reports from highly creative individuals, suggests that to prime your brain for creativity, you should first wander the world with an open mind. "Gathering a broad base of knowledge is the first stage of the creative process, which usually comes naturally to people through intellectual curiosity," Carson says. Another way to break your thought habits is by asking questions such as "How can I do this differently?" and by stepping outside your comfort zone. A poet with writer's block, for example, might be advised to take up a new hobby such as scuba diving or dance lessons. Neuroscientist-turned-artist Greg Dunn discovered an entirely different way to depict the brain when he began studying Sumi-e art, an Asian style of painting. His experimentation with the style's free-flowing ink led to a simple yet elegant new method for painting neurons.

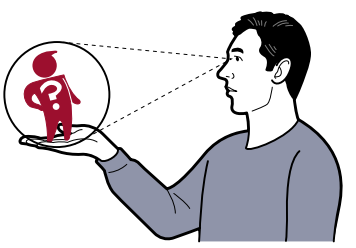
Yet simply exposing yourself to new things does not seem to be the full story. According to a study published in early 2018 by Sergio Agnoli and his colleagues at the Marconi Institute for Creativity at the University of Bologna in Italy, how you engage thoughts that arise through new experiences is important for facilitating creativity. They found that individuals who can deliberatively engage in focused mental exploration come up with more original solutions to problems than those who reported little ability to control how their mind wanders. Therefore, building a solid foundation from which creativity can grow requires both exposing yourself to new experiences and intentionally engaging with the thoughts and feelings that arise as a result.

## STAGE 2 : FOCUS

Psychologist Dean Keith Simonton of the University of California, Davis, has linked creativity with the acquisition of expertise [see his article "The Science of Genius," on page 4]. In 2000 Simonton compared the cumulative years of experience of 59 opera composers with their aesthetic success. He measured aesthetic achievement in eight different ways—tallying the number of times an opera was recorded and performed in major opera houses, for example, as well as the number of pages devoted to the work in opera histories.

Simonton found that a composer's years of musical experience were a powerful predictor of an opera's acclaim. He also found that if the composer had already created a number of other works within the same genre, this would actually hurt the opera's critical reception and legacy. In other words, solutions to great problems demand practice, skill and study, yet creative solutions occur when someone applies their experience to new domains.

Whether you are proving Fermat's last theorem or planning a birthday party, finding novel solutions involves a little advance research. How much preparation you need will vary, but the more you know about a problem, the better equipped you are to solve it. Some of the most creative minds in history were masters of their respective fields. Given that these people spent large amounts of time immersed in their studies, one of the best ways to maximize your creativity is to find an area in which you would like to develop an expertise. Then begin to follow that passion.





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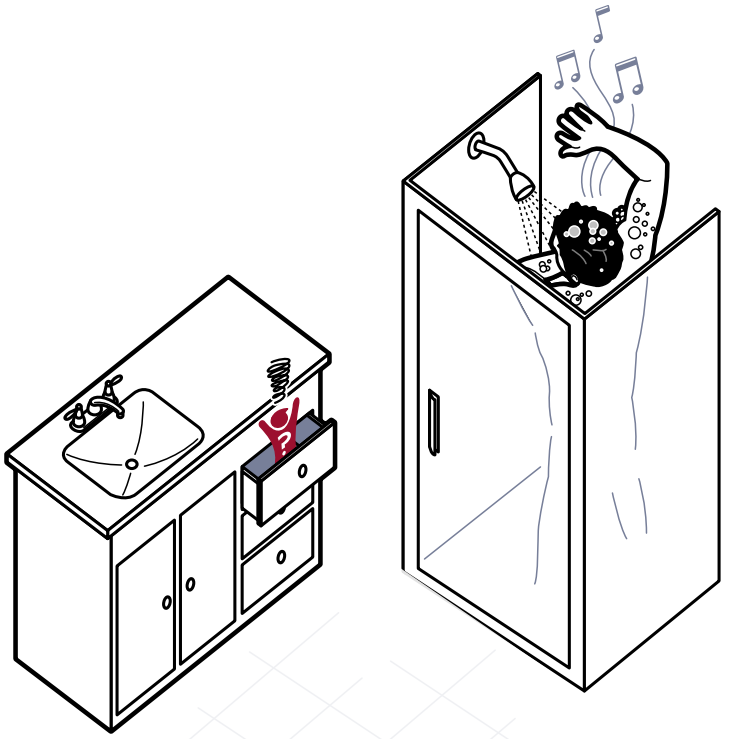


## STAGE 3 : INCUBATE

**Once you have immersed** yourself in a problem, the best way to come up with a creative solution is to stop consciously thinking about it. In 2006 Kounios and his colleagues used functional magnetic resonance imaging (fMRI) to record the brain activity of 44 men and women as they solved 185 remote-association problems. These word puzzles require finding a single word that can turn three seemingly unrelated words into familiar compound phrases; for example, the solution to "foam," "deep" and "salt" is "sea." After finding an answer, the subjects reported whether they had solved the problem using insight or analysis.

Kounios found that in the two seconds before a problem appeared, the insight users prepared for the challenge by shifting from their scattered outward attention to an inward focus. Puzzles solved insightfully were preceded by increased activation in the anterior cingulate cortex, a brain region that monitors internal attention to different ideas, among other things. In contrast, tasks solved analytically were preceded by significant activation in the occipital lobe, which, as mentioned earlier, handles visual processing. This increase indicates that the analytical solvers concentrated more on what they were looking at.

Research from the University of Amsterdam and the University of Bologna in Italy has demonstrated that sleeping on a problem or stepping away from it and then immersing yourself in an alternative activity can help you unconsciously cultivate creative solutions.

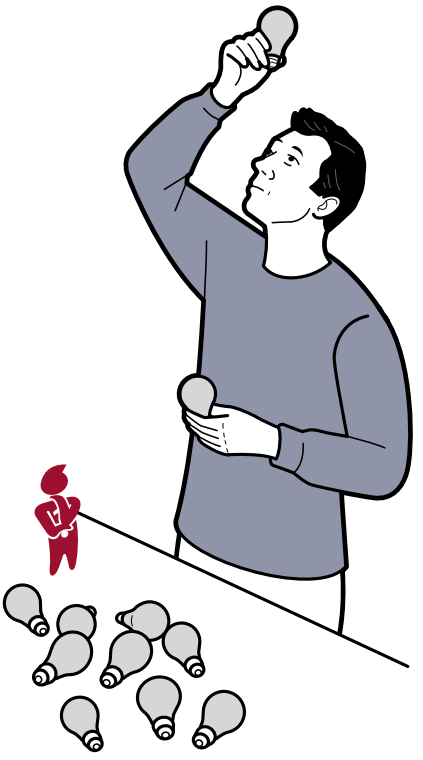
Taken together, the findings reveal a benefit to forcing your brain to shift gears or look within. One reason might be that your attention can then be captured by a surprising solution your unconscious mind has been ruminating on. So take a nap or try your hand at something new.

History is replete with examples of creative individuals who describe being hit with inspiration while daydreaming or attending to a different task. Writer Robert Louis Stevenson and musician Paul McCartney, for instance, used dreams as starting points for new works. Many day-to-day problems can be solved this way, which explains why so many people recall stumbling on ideas while taking a shower, driving to work or simply walking down the road.

## STAGE 4 : INSIGHT

**When insight hits**, certain changes happen in the brain. Psychologist Mark Beeman of Northwestern University led a study in 2004 that measured people's brain activity with fMRI and EEG during the moment of insight. As in Kounios's studies, participants tackled remote-association problems and then indicated if they had cracked the problem using insight. The results showed significantly increased activity in the anterior superior temporal gyrus of the right hemisphere at the critical moment when the solution appeared, in comparison to problem solvers who did not experience such an aha! moment. This gyrus is a prominent ridge on the cortex of the right hemisphere and plays a fundamental role in recognizing distant connections between words.

The activity surge in the right but not the left lobe may also be meaningful. According to the researchers, there are areas in the right side of your brain that interpret information more loosely than areas in the left side. This means that the information is less tightly defined, allowing you to





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access other concepts more readily, which is a key component of creativity. Both hemispheres are working all the time, but parts of your right hemisphere might loosely define a cat as a mammal, making it easy to see how a cat relates to, say, an elephant. Parts of your left hemisphere, however, might describe a cat as a small, carnivorous mammal with soft fur, a short snout and retractile claws—something very different from an elephant.

Research has suggested that you can tip the scales toward a looser style of understanding by describing objects or issues in unusual ways. For example, by thinking of a hanger as a long, twisted wire instead of as a metallic instrument for hanging coats, you might discover other uses for it. Try this technique every so often as you are actively working to solve your problem. It might help prime your brain to forge connections between distant concepts.

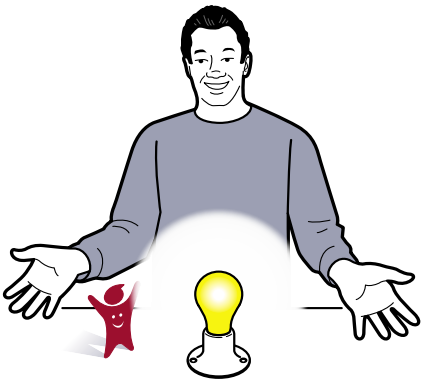
The moment of insight is also accompanied by a burst of alpha activity in the visual cortex, according to Beeman's study. Alpha activity, as mentioned earlier, inhibits neuron firing, meaning that during a breakthrough, your brain is less involved in processing visual information—perhaps because visual stimuli can be distracting. These findings suggest that you could help your brain discover an insight simply by closing your eyes.

Probably the most famous moment of insight in history is Archimedes' "Eureka!" Legend has it that the ancient Greek mathematician had been challenged to figure out whether a crown that King Hiero II of Syracuse had commissioned was made out of solid gold. Archimedes was preparing a bath when he discovered how to measure an object's volume, and thus its density, after noticing the displacement of water as he climbed into the tub. Although the story may be apocryphal, it has gone down in history in part because it illustrates perfectly how insight strikes.

## STAGE 5 : FOLLOW-THROUGH

Once you have had a moment of insight, you might find yourself feeling elated. A 2013 study by Tufts University researcher Tad Brunyé showed that subjects who came up with broad associations between words, such as associating "pipe" with "flute" rather than with "smoke," experienced a boost in mood. Take advantage of the positive mood to check whether your solution works. "When you have an insight, it comes with a lot of conviction," Carson says. "So you really have to be objective and evaluate that idea."

This stage is an ideal time to bounce ideas off of trusted friends—their feedback and support could help you determine how well your solution works [see "Creativity Is Collective," by S. Alexander Haslam, Inmaculada Adarves-Yorno and Tom Postmes, on page 52]. Do not be discouraged, though, if your personal eureka is less than perfect. Creative people often describe going through many failures before reaching a successful solution. Those failures help to inform the end result, making them a necessary step in the process. When a student asked chemist and two-time Nobel laureate Linus Pauling how he came up with so many good ideas, he replied, "I have a lot of ideas and throw away the bad ones."



In practice, each stage does not always follow easily from the one before it—many people have to revisit earlier steps several times before hitting on inspiration—but ultimately the process is very rewarding. Creativity not only makes creators happy but also benefits all those who will enjoy their creations.

The joys of an aha! moment may even serve a deeper purpose. In 2013 psychologists Claudia Muth and Claus-Christian Carbon of the University of Bamberg in Germany found that participants who identified a hidden face in a picture liked the image more than those who did not identify the face. Muth hypothesizes that insight is rewarding for evolutionary reasons. She says, "It could explain why we explore the world and why we have interest in things that are new."

Being curious and pursuing creative endeavors provides you with the opportunity to discover new interests, explore unfamiliar territory, develop expertise and, crucially, take breaks. In short, working to develop and maximize your creativity serves to enrich your life. As Carson puts it, "Once you realize that you can be creative, it opens up this whole new world." SA

**Nessa Bryce** is a clinical psychology Ph.D. candidate at Harvard University. Her work explores how childhood experiences, particularly traumatic ones, shape our brains and thus how we understand and interact with the world around us.

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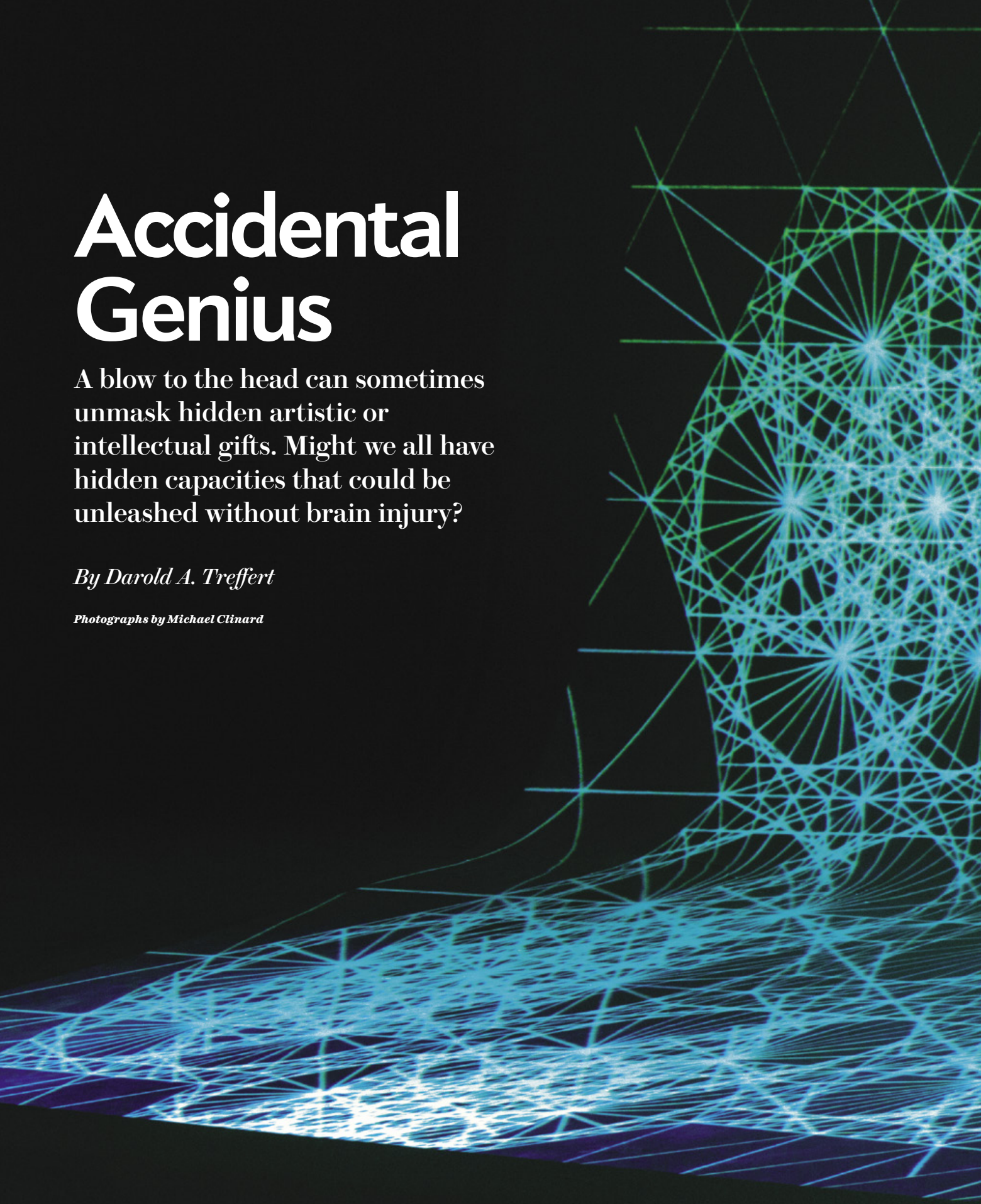
# Accidental Genius

**A blow to the head can sometimes unmask hidden artistic or intellectual gifts. Might we all have hidden capacities that could be unleashed without brain injury?**

*By Darold A. Treffert*

***Photographs by Michael Clinard***





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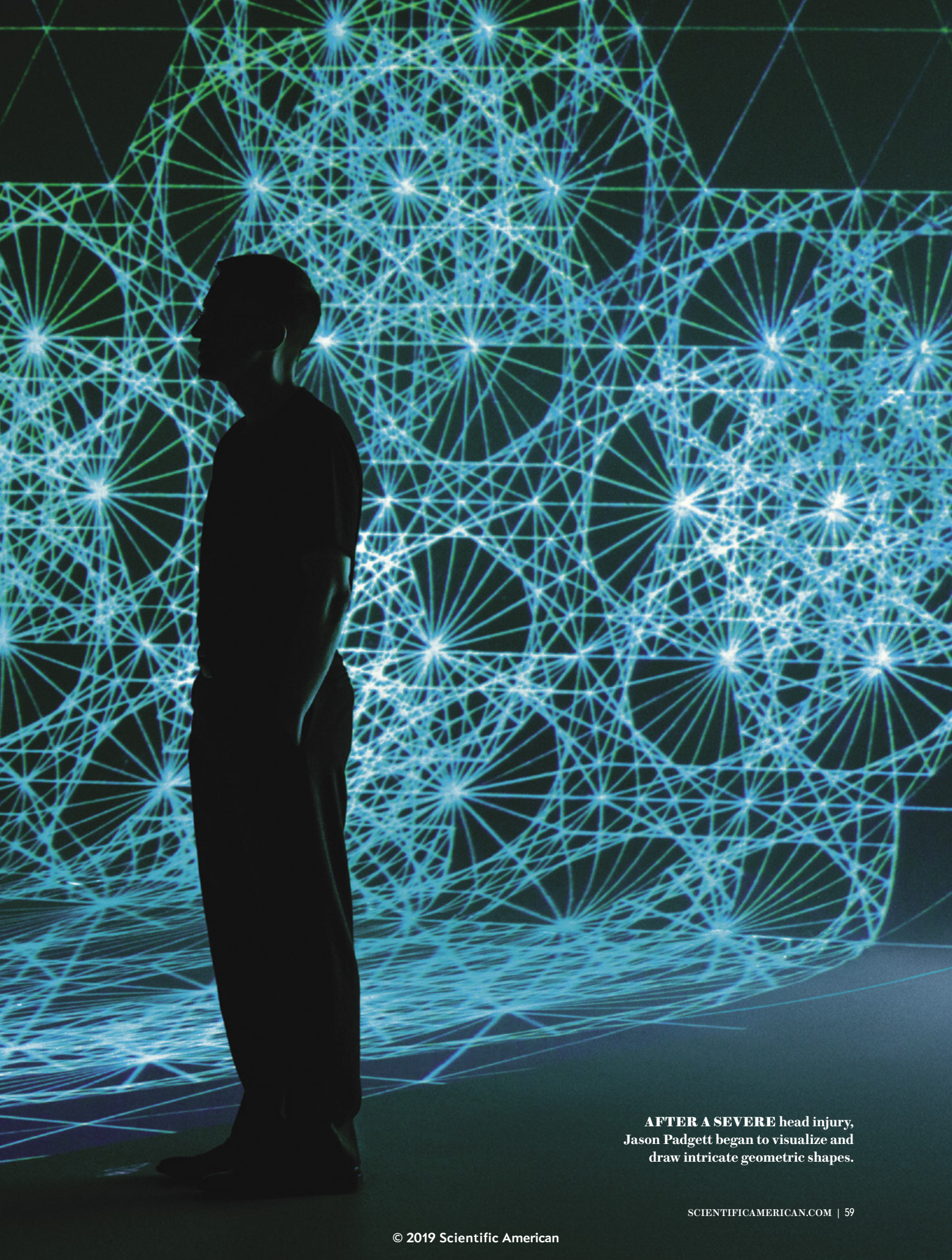

**AFTER A SEVERE** head injury, Jason Padgett began to visualize and draw intricate geometric shapes.



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A 10-YEAR-OLD BOY, ORLANDO SERRELL, KNOCKED UNCONSCIOUS one day by a baseball, discovered afterward that he could bring to mind the exact day of the week for any date after the accident and could remember the weather for each day since the trauma as well. He could also recall the most minute daily events. Jason Padgett, the victim of a brutal mugging in 2002 that left him with a severe concussion, soon afterward began to see what he describes simply as "images." He began to sketch them out on paper. When he showed his work to others, he learned that the repeating, self-similar patterns were fractals.

These two people have a remarkable condition known as acquired savant syndrome. In the more familiar form of savantism—made famous by the 1988 movie *Rain Man*—people are endowed from early in life with extraordinary but narrowly defined musical, artistic, mathematical, memory and mechanical skills that stand in contrast to their marked impairments in language, social interactions and other mental faculties overall. In *Rain Man,* for instance, actor Dustin Hoffman's character, Raymond Babbitt, has stunning mathematical, calendar-calculating and other skills and a massive memory but also shows severe cognitive and behavioral limitations from his underlying autism.

In acquired savant syndrome, in contrast, near-genius levels of artistic or intellectual skills show up after dementia, a severe blow to the head or another insult to the brain. Discovery of this unusual phenomenon raises the possibility that dormant potential in some artistic or intellectual realm—an "inner savant"—resides in each of us. If so, perhaps a way can be found to tap these buried abilities in the absence of disease or injury.

## YOUR INNER SCULPTOR

I HAVE STUDIED SAVANT SYNDROME for much of my career. Until the mid-1980s, I assumed it was present from birth—in other words, savant syndrome was a congenital condition. But then I attended the premier exhibition of exceptional sculptures made by Alonzo Clemons. As an infant, Clemons seemed to learn quickly. At about age three, however, a fall resulted in a brain injury, slowing his cognitive development precipitously and leaving him with a serious intellectual disability, including limited vocabulary and speech. But afterward, he developed a spectacular skill for sculpting, using whatever materials were handy—even shortening from the kitchen. With his new talent came a growing fascination with animals. For example, he could look at a photograph of a horse in a magazine and then sculpt a three-dimensional replica in less than half an hour, each muscle and tendon reproduced in exacting detail.

Clemons sparked my interest in acquired savant syndrome, and I looked for reports of it in the medical literature but found only a few instances. In 1923 psychologist Blanche M. Minogue

### IN BRIEF

***Rain Man,*** the movie starring Dustin Hoffman, brought to popular attention the existence of savant syndrome—in which people with autism display exceptional intellectual or artistic gifts from birth.

**Acquired savantism** is an alternative form of the condition in which a person develops skills such as the ability to paint, play music or do mental calculations after experiencing some form of brain injury.

**An inner savant** may exist in most people if the proper brain circuits are activated or switched off through electrical stimulation technologies or even through focused practice of a particular skill.



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**JASON PADGETT** began to produce drawings like the ones shown when a mugging that caused a concussion unlocked math, physics and artistic capabilities that the college dropout never knew he had.

COURTESY OF JASON PADGETT (*artwork*)

described the appearance of extraordinary musical abilities in a three-year-old following a bout of meningitis. In 1980 T. L. Brink, another psychologist, reported on a nine-year-old boy in whom superior mechanical skills appeared after a bullet wound to his left brain. In his case, he was able to dismantle, reassemble and modify multigear bicycles and invented a punching bag that could simulate the bobbing and weaving of a live opponent.

These sparse reports in the years before 1980 reflected the condition's rarity: a concussion or stroke does not usually enhance cognitive or creative capacity. I then decided to collect descriptions of such cases. By 2010 I had assembled a worldwide registry of 319 known savants, of whom only 32 had the acquired form. As of 2018, there are 91 recorded cases of acquired savantism.

Among the reports entered in my registry was work done by neurologist Bruce Miller, now at the University of California, San Francisco, and his colleagues. In 1996 Miller began compiling the first of 12 cases of people who had a disorder known as frontotemporal dementia (FTD). These elderly patients demonstrated musical or artistic skills for the first time, sometimes at prodigious levels, after their diagnosis. Frontotemporal dementia differs from Alzheimer's dementia in that the degenerative process affects only the frontal lobes and not wider areas of the brain.

FTD often targets the left anterior temporal area of the brain and the orbitofrontal cortex. Both regions normally inhibit activity in the visual system at the back of the brain, which is involved in processing incoming signals from the eyes. The disease seems to foster a newfound artistic sensibility by turning off inhibitory signals from the front of the brain. The releasing of the brakes allows the brain to process sight and sound in new ways. It unleashes artistic or other creative sensibilities even though damage to the frontal lobes may lead to the inappropriate behaviors that characterize the disorder. "FTD is an unexpected window into the artistic process," Miller says.



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## The Ultimate Eureka Moments

**Acquired savantism** has given people the ability to pursue poetry, music and instantaneous mental calculations. A few cases from a registry of savants follow:

**The late Tommy McHugh** was a 51-year-old builder in Liverpool, England, without any particular interest in poetry or painting. In 2001, after suffering a hemorrhage in the lining of the skull that damaged the frontal area of his brain, he suddenly began to fill notebooks with poems and to spend much of his time painting and sculpting. Physicians attributed this new talent to "relative disinhibition," which frees up the ability to evoke unusual word juxtapositions or imagery. McHugh had exhibits in the U.K., and his story was chronicled in a number of television documentaries.

**Orlando Serrell,** mentioned earlier, who began doing calendar calculations as a boy after being knocked out by a baseball, can determine the day of the week for any day since the injury occurred. He also recalls the weather every day since his injury. Now at 50, the Virginia man is still able to calendar-calculate, but his memory skills have advanced so that he can remember the minutest details of each day's activities—a condition known as hyperthymestic memory. Brain scans at Columbia University Medical Center have confirmed that Serrell engages in unconscious calculating—and his skill is not based on memorizing the calendar.

**Derek Amato** was a 40-year-old corporate trainer in Colorado with no special interest or skill in music. In 2006 he dove into the shallow end of a swimming pool, sustaining a severe concussion and losing some hearing in one ear. Following his hospital discharge, he was inexplicably drawn to the piano, which he had never touched before. He began to see black-and-white spots that he was able to transpose from his head into notes on the piano. He now makes his living composing, performing and recording.

**Tony Cicoria,** an orthopedic surgeon from New York, was talking on the telephone in 1994 when he was struck by lightning. Presumed to be in cardiac arrest, he was resuscitated by a nurse who was waiting to use the phone. For a week or two he had some mild memory problems. Those eventually subsided, and he resumed his orthopedic surgery practice full-time with no residual effects from the lightning strike. But one thing had changed. He developed a consuming obsession with classical music. Before the incident, he thought of himself as mainly a "rocker." But his newfound obsession morphed into a desire to play classical music as well. Shortly after his injury, he heard music in a dream. The tune stuck with him, resonating in his head whether he was awake or asleep. Finally, he decided to transcribe the earworm into a 26-page concert piano piece called *Fantasia: The Lightning Sonata, op. 1.*

**Jason Padgett,** who developed a passion for math, physics and drawing geometric shapes after he sustained a concussion following the assault mentioned earlier, still runs three futon stores in Washington State. He now calls the injury a "rare gift." Before the mugging, Padgett described himself as being among the "math-averse." Now the former college dropout takes higher-level math courses to fully understand the geometric figures that are his obsession, and he has written a popular book about his experiences.

*—D.A.T.*

Further work implies that accidental genius results from diminished activity in some brain areas that is combined with a counterbalancing intensification in others. More specifically, it involves a set of events I call the three Rs that occur after the brain is damaged—most often after the left hemisphere is stricken, similar to what happened with Miller's FTD cases. The process begins with "recruitment," a rise in electrical activity in still intact cortical tissue, often in the right hemisphere. Then the brain circuitry undergoes "rewiring" to establish newly formed connections between regions that were not previously linked. Next comes "release" of dormant capacity as a result of increased access to the newly connected brain areas.

An experiment done by Richard Chi and Allan Snyder, both then at the Center for the Mind at the University of Sydney, has used a relatively new technology to provide some evidence that these brain changes account for the acquired savant skills. Using transcranial direct-current stimulation (tDCS), these researchers induced savantlike abilities in human volunteers. The technique generates a polarized electric current to diminish activity in a part of the left hemisphere involved with sensory input, memory, language and other brain processes while increasing activity in the right hemisphere (the right anterior temporal lobe).

The investigators then asked study participants to solve the challenging "nine-dot" puzzle either with or without tDCS—a task that requires the creativity to search for a solution in an unconventional way. Participants had to connect three rows of three dots using four straight lines without lifting a pen or retracing lines. None of them could solve it before stimulation, and when 29 subjects were exposed to "sham" stimulation—electrodes emplaced without any current to test for placebo effects—they were still at a loss. With the current switched on, however, some 40 percent—14 of 33 participants—worked their way through the puzzle successfully.

How can a person suddenly perform so much better at the flip of a switch? Because these instant savants—and congenital and acquired savants as well—"know things" innately they were never taught. Clemons, the sculptor, had no formal training in art but knew instinctively how to produce an armature, the frame for the sculpture, to enable his pieces to show horses in motion.

One plausible explanation for the hidden talents that emerge in savant syndrome—whether early in life or induced by injury—is that these reservoirs of skill and knowledge must be inherited



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in some way. We do not start life with a blank slate that subsequently gets inscribed through education and other life experiences. The brain may come loaded with a set of innate predispositions for processing what it sees or for understanding the "rules" of music, art or mathematics. Savants can tap into that inherited knowledge far better than the average person can.

### THE GENIUS SWITCH

KNOWING THAT THESE TALENTS can emerge even later in life raises the question of whether everyone has the capacity to become a savant—and whether it might be possible to do so without facing the travails of brain injury or dementia.

Another way to unleash buried brilliance would be to apply tDCS—or a related technology called repetitive transcranial magnetic stimulation—as a form of "thinking cap" that would toggle brain regions on and off to potentially augment a person's creative capacity. A technological solution may not be an absolute prerequisite, however. Meditation or simple adherence to assiduous practice of an artistic skill may suffice to allow us to switch on the more creative aspects of the brain and thus explore undiscovered artistic capabilities.

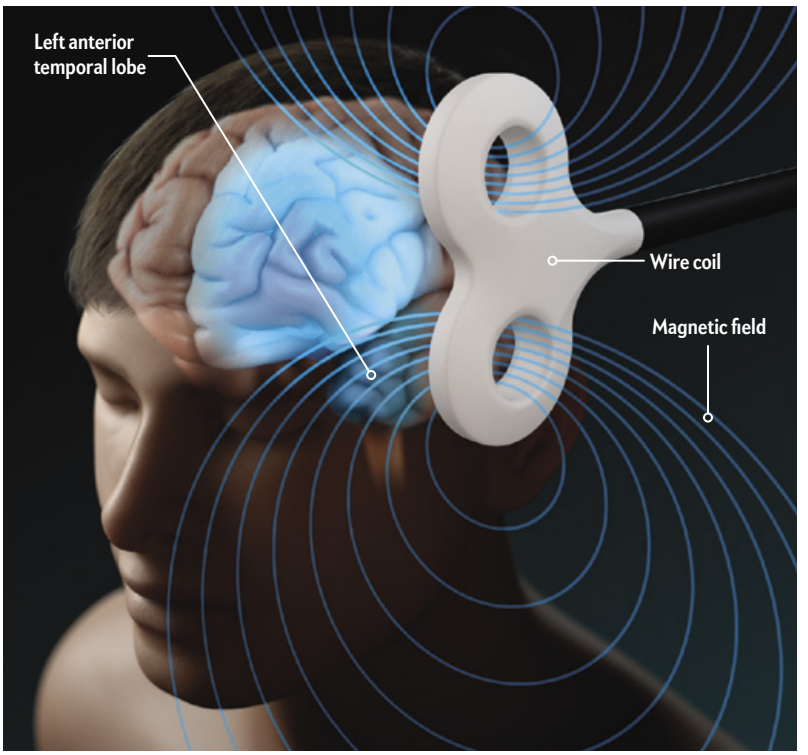
As investigators understand the brain better, they may find other ways of determining what happens when brain circuits are turned up or down. Diffusion tensor imaging (DTI) and diffusion tensor tracking (DTT), which pinpoint connections among neurons ("fiber tracking"), are better suited than earlier methods for revealing the intricacies of the wiring inside a person's head, enabling researchers to correlate brain activity to the sudden appearance of skills. These more precise technologies can provide three-dimensional images of the fibers that tie together brain cells.

One challenge to uncovering the neurobiology underlying savantism has been the difficulty of observing brains as they carry out creative tasks that require movement. Not only is it hard to sculpt or play a piano inside an MRI machine, but any movement compromises image acuity. A newer technique—near-infrared spectroscopy (NIRS)—would sidestep such problems by replacing bulky machines with a comfortable skullcap that measures the amount of oxygen in blood flowing through the brain's blood vessels and relays the information to image-processing software. Even more promising is a recently developed helmet that uses another imaging method—positron-emission tomography (PET)—for monitoring when a person is sitting, standing or even exercising.

Such studies are worth pursuing. Acquired savantism provides strong evidence that a deep well of brain potential resides within us all. The challenge now is to find the best ways to tap into our inner savant—that little bit of *Rain Man*—while keeping the rest of our mental faculties intact. SA

## Instant Savant

A technology called repetitive transcranial magnetic stimulation can temporarily unleash savantlike abilities and offers a way to investigate how those abilities arise. When a coil placed over the left temple delivers a pulsed magnetic field through the skull, the field apparently turns off brain circuits in the left temporal area that process words and other information. Right-brain circuits dedicated to spatial tasks take on a more expansive role in mental processing. In some cases, subjects exposed to the magnetic fields were better able to guess the quantity of a large collection of objects.




**Darold A. Treffert,** a psychiatrist, met his first savant in 1962 and continues research on savant syndrome at the Treffert Center in Fond du Lac, Wis. He was a consultant for the 1988 movie *Rain Man* and maintains a Web page at www.savantsyndrome.com, hosted by the Wisconsin Medical Society.

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# Nurturing the Young Genius

Renewing our commitment to gifted and talented education is the key to a more innovative, productive and culturally rich society

*By Rena F. Subotnik, Paula Olszewski-Kubilius and Frank C. Worrell*



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IN 1957, WHEN SPUTNIK TOOK THE WORLD BY STORM, THE FORD FOUNDATION was several years into a project for talented students based on early college entrance. An evaluation of that program from the Fund for the Advancement of Education read: "There are those who argue that it is psychologically unsound and politically undemocratic for one child to proceed faster or to have a richer academic diet than another.... But what is too often ignored is the greatest risk of all—the risk of adhering stubbornly to a clearly imperfect set of practices which are frustrating the development of young talent at a time in history when this nation urgently needs to develop its human resources to the full."

IN BRIEF

**Abilities matter,** particularly abilities in specific domains. They are malleable, however, and need to be cultivated.

**Society needs** to provide opportunities for intellectual enrichment to all students to ferret out hidden talents.

**Psychological strengths** such as persistence, social skills and strategic risk-taking are determining factors in the successful development of talent. Being psychologically strong ensures that more children and youth have the wherewithal to take challenges and opportunities that are offered.

The authors argued that, in a democracy, focusing on the *most* able students is critical for nurturing a cadre of capable leaders, among other advantages. The resulting infusion of attention and resources to talented youth through the National Defense Education Act led to a boom of innovation and scientific productivity in the U.S.

Today researchers, policy makers and teachers pay little to no attention to high-achieving students. School-based gifted education receives scant state or federal funding. Only four states fully fund their mandates to identify and serve gifted students. Many such students spend their days in school unchallenged—relearning material they have already mastered. The failure to develop talented students means that fewer of them will become future innovators of products and services; creative thinkers to solve major social, economic and environmental problems; leaders to tackle national priorities; or performers to entertain, inspire and soothe our souls.

America's neglect of its talent is showing, particularly where math is concerned. Percentages of top-performing 15-year-old students—those with a mastery of the most complex high school mathematics—ranged from 35 percent in Singapore to nearly 0 percent in Peru, Mexico, Colombia, Costa Rica and Jordan. In the U.S., 6 percent of 15-year-old students scored at that level or above, which was lower than the Organisation for Economic Co-operation and Development average of 11 percent.

We think a renewed commitment to gifted education is critical for expanding the pool of individuals who can make pathbreaking discoveries and creative contributions to our society. The first step is to train teachers and others to spot talent, which may show up in a child's IQ score but could also surface as aptitudes in specific areas such as number sense or musical ability. Psychosocial skills that can be developed through training, such as persistence, strategic risk-taking and self-regulation, also contribute to later success.

Offering young children a wide palette of activities could spawn new interests and enable a greater diversity of talents to surface. Once an exceptional aptitude emerges, we need programs to be in place, including accelerated classes and psychological coaching, that can nurture its development as early and vigorously as possible. The chief goal of these efforts is preparing young people for outstanding achievement.

## TALENT

FOR NEARLY A CENTURY scholars have sought to understand, measure and explain giftedness. To some, the term is a misnomer for the result of endless practice or social advantage. We believe, however, that extraordi-

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nary abilities do exist and do matter. Giftedness implies an ability to perform at the extreme upper end of the distribution in a certain area. Early on it is determined and largely defined by potential, followed by demonstrated achievement and, later, by creative productivity or eminence. In elementary schools, it is often equated with IQ. Students who score above the 95th percentile (although cutoffs vary) on an intelligence test are often classified as gifted.

IQ is generally predictive of achievement in school, but new research shows that narrower, subject-specific academic assessments can help forecast the likelihood of adult contributions to, say, literature or physics. In 2005 psychologist David Lubinski of Vanderbilt University and his colleagues reported that scores on the math and verbal parts of the SAT measured around age 13 in high-achieving students (as well as tests of student interests) can indicate whether an adolescent will choose to later pursue the humanities or a math or science field as a career. Even differences within the 99th percentile of scores for mathematical ability—the top 1 percent—are associated with variations in outcomes, such as a student's eventual income level, number of patents and other creative accomplishments, and the likelihood of obtaining a doctorate. This longitudinal work is ongoing in 2019 and has been replicated at Duke University.

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In recent years educators have begun to look beyond IQ scores to measure giftedness. Specialized schools or programs for science or the arts admit students based on achievement-test scores, essays and projects. Elementary school programs may ask teachers to complete checklists that reveal a student's commitment to learning. As we discover how to better identify the core abilities associated with each domain of knowledge and skill, the field will move from relying primarily on current performance to using measures of potential, including psychosocial skills as students get older.

The nonacademic domains are more advanced on this front. For example, New York–based choreographer and ballet dancer Eliot Feld, who has had years of experience building dance troupes and educating novice performers, identifies potential dancers around the age of eight using indicators of flexibility, body proportion and physical memory. Characteristics such as pitch perception and audiation—a way of cognitively processing music—have been associated with musical performance. In response to a survey, voice teachers identified intonation, timbre, musicality and pitch control as important factors related to singing talent.

Our ability to identify and assess the aptitudes that matter varies, however. In athletics, dance, music and chess, experts have developed visible benchmarks of talent at various ages. In academics, so far only in mathematics have we begun to generate reliable ways to detect potential talent early on.

## COMMITMENT

TO ACHIEVE GREATNESS in any realm requires more than talent. It also demands extraordinary creativity, self-regulation and social skills. Creativity, the ability to come up with novel, useful and elegant ideas or ways of doing things, has a long historical association with giftedness. It may depend on relevant skills and knowledge, but at its essence are mental processes such as metaphorical thinking, tolerance for complexity and flexibility in problem-solving.

Precursors of adult creativity may include independent thinking, a willingness to entertain different perspectives and views, and the creation of projects and products that are novel when compared with those of one's peers. In 1999 educational psychologist Jonathan Plucker, now at Johns Hopkins University, reported results from a multidecade follow-up of students identified as creative with the Torrance Tests of Creative

**PROVIDING MORE opportunities for gifted children will boost our supply of future leaders, creative thinkers and inspiring performers and will thus greatly improve our lives.**



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Thinking while they were in elementary school. Scores on this test, which largely measures divergent thinking, were three times better than IQ tests at predicting the quantity and quality of publicly recognized creative accomplishments in adulthood.

Aside from their ability and creativity, gifted individuals stand out in the commitment and sacrifice they are willing to make in pursuit of their goals. In a chapter in a 1985 book entitled *Advances in Motivation and Achievement,* psychologist Mihaly Csikszentmihalyi wrote, "The unifying similarity among geniuses and innovators is not cognitive or affective but motivational. What is common among them is the unwillingness or inability to strive for goals everyone else accepts."

Giftedness has long been associated with high levels of intrinsic motivation—that is, engaging in a task for the sake of learning. In fact, many high academic achievers are also motivated by and enjoy extrinsic factors such as trophies, scholarships and other forms of recognition. In a 2010 study school psychologist David J. Kover, then at the San Francisco Unified School District, and one of us (Worrell) showed that a group of academically talented students had similar levels of intrinsic and extrinsic motivation. High achievers may hunger more than others not only for knowledge but also for fame, fortune or power to change the world.

In 1978 Joseph Renzulli introduced the idea that one of the most distinguishing features of high achievers is their task persistence and motivation. In other words, they are willing to engage in study and practice that, though not necessarily enjoyable, is instrumental to improvement. In a 2008 study, psychologist Timothy W. Curby, now at George Mason University, and his colleagues demonstrated that the kindergarten pupils most likely to be identified as gifted in third grade exhibited not only high cognitive ability but also early task orientation, which is "the ability to do and complete work even in an environment in which teachers may not be directly supervising the work or when there are distractions present." In findings published in 1990 psychologists Camilla P. Benbow and Olya Arjmand, then at Iowa State University, used a statistical method to determine variables that distinguished between high and low achievers in mathematics among 356 students identified as mathematically gifted based on their SAT scores. Their analysis revealed that the strongest long-term predictor of high achievement in a related area—going to medical school or graduate school for math or science—was the number of optional math and science examinations the students had taken, a variable that reflects a *commitment* to the discipline.

Passion contributes to the development of great ideas and performances, although it has been rarely studied in the context of gifted education. In one exception, psychologist Jennifer A. Fredricks, then at Connecticut College, and her colleagues examined the quality in a 2010 study of 66 high school and college students who had been identified as gifted in academics, sports or the arts in childhood. The athletes and artists readily expressed passion about their involve-

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ment, telling experimenters, for instance, "I love the game … I want to play all the time." Among academically gifted youths, however, a typical statement was: "Well, I don't get all excited or anything—I mean, it's schoolwork." The study suggested that the way academics are currently taught does not instill passion, but with a greater focus on problem-solving, creative thinking and learning authentic methods of a discipline, we might better foster that passion among academically gifted students. Further, the students might have displayed interest in specific subjects if the survey had been structured that way.

## OPPORTUNITY

ALTHOUGH THE GOAL of education in the U.S. is for all children to maximize their potential, the focus of funding has primarily been on the most vulnerable children, such as those with disabilities, who are rightly guaranteed a free appropriate public education. Educators and policy makers assume that academically gifted children will be successful no matter what their educational environment. Yet research has shown that it takes both opportunity and guided study or practice to reach levels of expertise in most domains. Although substantial numbers of children with outstanding intellectual ability are singled out and receive at least some support, few of these youngsters become eminent in adulthood, suggesting that many are not receiving the guidance and instruction they need to fulfill their potential.

A key to developing this talent may lie in giving students lots of opportunities to pursue their interests. In a 2010 study Jonathan Wai, then at Duke, and his colleagues assessed participation in various educational opportunities such as academic competitions, research apprenticeships, academic clubs, summer programs and accelerated classes among 1,467 individuals who had been identified as talented in math at age 13. They found that those who had been involved in more of these activities and classes—what the authors called a larger "educational dose"—had, at age 33, a higher rate of notable accomplishments in science, technology or math, such as earning a Ph.D., obtaining patents or securing tenure.

Effective talent development requires different kinds of teachers at different stages. Mentorship is vital for transforming ability into renown. In a study of the origins of eminence through mentorship published in 1977, sociologist Harriet Zuckerman of Columbia University interviewed 92 Americans who had won a Nobel Prize in science between 1901 and 1972. She found that more than half the interviewees had studied or collaborated with previous laureates. These mentors helped their protégés develop a feel for important problems and elegant solutions and mobilized resources, such as access to grants, fellowships, jobs and publications, on their behalf.

Developing youthful talents, especially in low-income and rural communities, by extending and supplementing the regular curriculum can expose children to

**ABILITY MATTERS for achievement, but expertise in any domain requires opportunity and hard work. Recent data suggest that many gifted children are not receiving the guidance and instruction they need to fulfill their potential.**



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**GIFTED KIDS** may be intrinsically driven, but they want public recognition, too. Schools tend to celebrate academic accomplishments far less than those in, say, athletics. Finding ways to cheer on or celebrate intellectual feats could encourage high academic achievement.

new topics and ideas and enable them to engage with a subject in more depth. Summer programs, for example, may feature a range of topics that are not typically available in the regular classroom, such as human anatomy for fourth graders and robotics for middle schoolers.

Such enrichment activities are a staple of most gifted programs in schools, but expanding them could ferret out new talent. Courses that introduce subjects typically not studied until high school or college, for example, may give interested and able students a head start. In some cases, students may take these courses in specialized schools for gifted students such as the Illinois Mathematics and Science Academy and New York City's Brooklyn Technical High School and Bronx High School of Science.

The greater the diversity of offerings, the greater are our chances of unmasking potential. In 2004 the news program *60 Minutes* ran a piece on low-income adolescents of color from Harlem, four of whom were representing the U.S. at the Olympics in fencing that year. How did students from low-income backgrounds living in an inner-city neighborhood get involved in such an esoteric sport? By good fortune, a former African-American fencing champion had retired to Harlem and began giving lessons 15 years earlier. His work provided the opportunity for many youngsters who may never have held a sword to discover that they had a talent for the sport (as well as the interest, passion and commitment to pursue it).

Students who seize such opportunities and demonstrate sufficient commitment should be given access to increasingly challenging classes or competitions, regardless of their age. Academic acceleration may involve skipping a grade, entering a higher grade level in a single subject or enrolling early in Advanced Placement courses. It may also consist of speeding up instruction in a course so that two years of material are covered in one year.

Acceleration significantly boosts both achievement and motivation in gifted students. Several meta-analyses reported in 2004 by psychologist James A. Kulik found that accelerated elementary and secondary students demonstrated levels of achievement superior to mainstreamed gifted students of the same age and ability. Kulik also found that accelerated students were more likely to seek degrees beyond a bachelor's. Researchers Saiying Steenbergen-Hu and Matthew C. Makel of Northwestern University and one of us (Olszewski-Kubilius) conducted a meta-analysis of the effects of acceleration, based on six previous meta-analyses. Results showed that the accelerated students significantly outperformed their nonaccelerated same-age peers, to at least a moderate degree, although their performance was not significantly greater than that of their nonaccelerated older peers. When different forms of acceleration were studied separately, such as grade skipping or compressing curriculum into shorter periods, results were similar, with positive, moderate and statistically significant impact of acceleration on students' academic achievement.

Schools hardly ever use acceleration strategies. Yet acceleration should be a key part of gifted education.

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Indeed, we can expect children with talent to increasingly channel their efforts into specific areas as they mature. They may be able to do so by buying time for enrichment, apprenticeships and other exploratory programs through showing early mastery of content. Students benefit from schools staffed with extremely knowledgeable teachers even at the earliest grades, and we need more affordable summer programs that compress semester-long or yearlong courses into a few weeks of intensive instruction.

## PERSISTENCE

PROVIDING OPPORTUNITIES is not enough, however. Talented individuals must take advantage of them. Research shows that young people may shy away from educational or extracurricular offerings for various reasons, including fear of competition and failure, poor study and organizational skills, and shyness. Capitalizing on favorable circumstances thus requires certain psychological strengths, among them an ability to cope with challenges and criticism and a willingness to take strategic risks.

Such traits, along with persistence, focus and drive, also support the ability to undergo the intense practice and preparation necessary to reach the top. In a 2001 study sports psychologist Daniel Gould of Michigan State University and his colleagues investigated the development of psychological strength in U.S. Olympic champions. Becoming a champion requires more than just athletic prowess. It also depends on an ability to focus, mental toughness, facility with setting goals, competitiveness, confidence, coachability, drive, optimism and emotional control.

Coaches routinely teach elite athletes how to handle setbacks, adjust anxiety levels for optimal performance and imagine success. In recent years music conservatories have given more systematic attention to these skills. The Juilliard School's precollege and conservatory programs implicitly inculcate values, such as deep devotion to one's art and teachers, that are associated with successful negotiation of the conservatory years. The school has also offered courses on mental-skills training to directly address variations in outcome, from music star to underachiever.

Academically talented students can experience competitive and occasionally stressful environments. Although these individuals often display extraordinary motivation and commitment, they rarely receive additional psychological coaching to deal with the rigors of acceleration, peer comparisons, and other challenges. School and college teachers receive no systematic training in this realm. Neither are they typically trained to boost creativity through exercises that invigorate metaphorical and divergent thinking or problem-solving.

Schools could do more to encourage high academic achievement, too. Although teachers and administrators often publicly recognize accomplishments in athletics, leadership and the performing arts, they tend to ignore or downplay academic feats. Stereotyping kids with intellectual talents as "nerds" or "brainiacs" betrays a lack of support for these children, many of whom work very hard to meet their goals. It may also send a message to other students that high achievement is not worthy of teacher attention or recognition.

Indeed, the idea that gifted children are "naturals" and do not need to study or practice can severely undercut motivation. According to research by psychologist Carol S. Dweck of Stanford University, the assumption that intelligence and talent are fixed traits can lead people to focus primarily on proving themselves worthy of their gifted or "smart" label and to undervalue the role of effort in achievement. In contrast, believing that intelligence and talent are malleable can motivate a person to put in the daunting amount of effort necessary to achieve goals such as becoming a respected physicist, historian or philosopher. Dweck's research suggests that this attitude can be fostered with proper instruction and parenting practices.

The aim of our proposed framework is to increase the number of individuals who can develop the innovative products and services and deliver the creative performances that can improve and enhance our lives. The world needs more of these people. We are not advocating that all services be channeled to those on the path to eminence. Yet a focus on eminence sustains a continued attention to excellence. When people are given the means to transform talent into transcendent achievement, they experience great personal satisfaction and, at the same time, deliver unimaginable benefits to society. SA

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# CAN YOU SUPER-CHARGE YOUR BABY?

Hundreds of toys promise to help babies read, learn, do math and walk earlier than expected—many without scientific backing

*By Erik Vance*

*PhotoIllustration by Dan Saelinger*



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WHEN SETH POLLAK'S SON WAS A YEAR OLD, HE AND HIS WIFE, Jenny Saffran, took a trip to the Babies "R" Us store near their home in Madison, Wis. They wanted to buy a teething ring—nothing special, just a frozen band to numb the baby's gums. Passing through the bears and bicycles, they found the correct display. They pulled a pricey package off the shelf, which read, "Promotes oral motor and language development."

The couple had never heard of such a claim, although it sounded important. Typical parents—worried about their child falling behind—might have bought the product without thinking. But Pollak and Saffran are not typical parents. "My wife is one of the world's leading experts in language development, and we are both Ph.D.s in developmental psychology," Pollak explains. "We are looking at this, and we're like, 'What the hell? How in the world does chewing on a cold thing promote language?'"

There is little evidence to say it does. And the claim is just one example of the disconnect between the research and marketing of child development.

Every parent wants his or her baby to have an early jump on life. Shouldn't toys be part of that? If your baby plays with the right gizmos during the right developmental window, the sales pitch goes, she or he could become smarter, more coordinated and more successful than other babies.

But the very idea that the purpose of a toy is to give your baby an edge "fundamentally misunderstands what's happening in development," says Alison Gopnik, a columnist and leading child psychologist at the University of California, Berkeley. Even if experts could devise such products, "we would have defeated the whole point of childhood," which, she asserts, is for the child to build himself or herself.

Whether it is a black-and-white mobile that supposedly catches a baby's eye or a caterpillar that teaches your toddler to code, American toys that promote child development are rampant. But do they work? Gopnik, along with many developmental psychologists, believes that there is a gaping hole between products and research. Too often toys come with claims based on either questionable science or none at all.

Yet the North American educational toy market is estimated at more than $4 billion in 2018 and is growing rapidly, according to research firm Technavio. Experts say that is because of a deep insecurity in American parents. Has their daughter breastfed too long? Not long enough? Is their son in the right preschool? If babies are not crawling, walking, talking, reading and even doing math early, then they are doing it late.

"Kids are surrounded by a panicked, kind of fearful culture. 'Oh, my God, you're falling behind,'" says Barbara Sarnecka, a cognitive scientist at the University of California, Irvine, who studies language and math acquisition.

Although scientists are fervently trying to understand how the human brain develops and how to help babies and toddlers

IN BRIEF

**So-called educational toys** make myriad claims about helping babies read, learn, do math and walk early, but little science backs them up.

**Even if infants** do achieve early milestones, research fails to show that a jump leads to any long-term advantages.

**Fast-paced video** imagery may lead to attentional problems. The greatest benefit from play comes from interacting with another human being.



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who are truly developmentally or socially lagging, many toy makers seem to suggest you can supercharge the average kid. Are there any findings that might support these claims?

## EARLIER IS NOT BETTER

MARKETING TO PARENTS' anxieties begins the moment sperm meets egg. Expectant mothers must carefully manage nutrition, vitamins and stress for fear that any mistakes might have lasting effects on their children. And of course, your fetus needs the proper music.

That's right: the fast track to a prized life starts with music in the womb. There are a number of products that come with speakers that attach to a woman's belly to play music. One gadget, Babypod, goes a step further: it is a bulb-shaped silicone speaker that is inserted inside the woman's vagina. The product site says, "Our initial hypothesis suggests that music… activates the brain circuits that stimulate language and communication. In other words, learning begins in utero."

It is true that babies learn while in the womb and that music is enriching to young children. But there is no evidence that music enriches a fetus. The creators of Babypod published a paper in the British Medical Ultrasound Society's journal *Ultrasound* showing that fetuses reacted more strongly to their product than to external speakers, but it did not conclude that the reactions were positive or that this strategy translated into smarter children.

**ALTHOUGH THE CHILDREN USING THE PROGRAM DID NOT ADVANCE, THEIR PARENTS WERE CONVINCED THEY HAD.**

"I know of nothing out there that says that this stimulation does anything for your baby," says Kathy Hirsh-Pasek, a developmental psychologist at Temple University and a former president of the International Congress of Infant Studies. Babypod did not respond to numerous requests for comment.

Hirsh-Pasek specializes in language acquisition in babies, which is a huge research area and a rich target for claims. She says she displays her least favorite toys marketed to anxious parents on a wall in her office.

Speaking is perhaps a baby's most important milestone and is tied to later cognition and working memory. Studies show that babies and young children have certain age windows during which these abilities blossom. Some evidence suggests that how quickly babies learn new words predicts later proclivity; loquacious children tend to be loquacious in later childhood, too.

But is earlier always better? Scientists have tried to tie early speaking to intelligence for decades. A 1982 study based in Ohio found early talkers often had higher IQs later in life. Interestingly, however, the effect disappeared when researchers controlled for cognitive problems and socioeconomic status. This insight, Hirsh-Pasek says, is the crux. Speaking early or late does not determine success; zip code does. Poverty, food instability and violence create stress, and stress delays speech and leads to academic disparity down the line. In many stressful homes, infants simply are not spoken to enough and thus suffer from a language gap that turns into a pervasive performance gap. Yet many toy makers turn this situation into an unfounded assumption: because lack of speech creates a deficit, extra speech will pay dividends.

Sarnecka says that is "just a fantasy—a fantasy that's profitable." Mental stimulation for young children is like vitamins—enough is important, but more is not better. Yet thousands of apps are available. And the average 18-month-old has at least seven DVDs.

"You think you've seen the worst, you know, and then something else hits the market," Hirsh-Pasek says. "One of my all-time favorites, of course, is Your Baby Can Read. To which I answer, 'No, she cannot.'"

Your Baby Can Read was a series of flash cards, videos and books that purported to teach children from three months to five years to read. The product was created by a researcher named Robert Titzer, who claimed to have taught his two daughters to read when they were babies. Conventional studies indicate babies simply cannot understand the written word. Yet the company selling the product offered impressive-sounding, though unpublished, studies and charts, alongside glowing testimonials, including one about a preschooler reading Harry Potter books.

Hirsh-Pasek was not the only one who noticed the aggressive advertising. The Federal Trade Commission, which polices claims, opened two cases involving Titzer, charging that companies he worked with were engaged in deceptive practices.

FTC lawyers reached out to Susan Neuman of New York University to learn more. Neuman is an expert in language acquisition. She had run a randomized controlled study comparing 61 babies who were exposed to Your Baby Can Read against 56 who were not and published the results in the *Journal of Educational Psychology*. Based on 14 measures, such as speech processing, word learning, letter recognition and reading with meaning, she found no difference between the two groups. Well, almost none. Although the children using the program did not advance beyond the others, their parents were convinced they had.

Titzer, for his part, told me he was never involved in marketing decisions and would never have suggested toddlers can read Harry Potter books. But he defends his product and says Neuman did not use it correctly and asked inappropriate questions to test the babies' learning.

In the end, Titzer and the companies settled with the FTC in 2014 for $800,000. The FTC also promised much larger fines should he make similar claims again. He now runs Infant Learning Company, which sells a set of DVDs, printed cards and books called Your Baby Can Learn! The company also sells a kit called Your Child Can Read!

As for the marketing, Titzer says it has changed: "We have babies *looking* at books. Everyone recommends that babies look at books, so I don't see anything wrong with babies looking at books."

Dozens of studies indicate that many video-learning programs fail to show reliable results. Titzer insists that his products are measurably superior and notes that he is working on a publication that vindicates them. According to FTC lawyer Annette Soberats, who spoke with a colleague who was involved



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in the Your Baby Can Read case, her agency considers the matter closed.

### FLASH CARDS + VIDEOS = MATH SKILLS

OF COURSE, toys do not exist in a vacuum. There is some pressure from consumers to make sure toys are educational, especially for the very young, says Clement Chau, an expert in child development and a director for toy company LeapFrog Enterprises. "I think there is a tendency to say, 'I want my kid to go to Harvard, so I'm going to buy them a toy from LeapFrog, and they will go to Harvard eventually,'" he says. That viewpoint may be unrealistic, but toys can still be an integrated part of learning, Chau adds.

In the end, it is not clear that parents can supercharge their baby to boost his or her long-term abilities. At least, that is what David Barner says. And he should know; he tried like crazy to supercharge his daughter.

Barner is an expert in the development of math education for children. He knows that math learning is important for cognition and life skills. So he wanted his two-year-old daughter to be a math whiz. He was never great at math himself—both he and his wife preferred reading—but he saw its value. So for months he spent time each day quizzing his child using products that utilize flash cards, videos, games and comic books to teach math to toddlers and preschoolers.

In the end, although he delighted in watching a young mind absorb math in real time, that is pretty much all he got, while his daughter developed a distaste for math. Her true passion and skill? Reading, of course.

Speaking with his professional hat on, Barner thinks that parents have less impact on their kids than "things like who your friends are, what school you go to, whether you have access to good resources." Many analyses, such as an ongoing University of Minnesota study with separated twins, also show that personality and proclivities are surprisingly heritable.

Barner's work has revealed that many kids between three and five who can count and even seem to do simple addition do not actually comprehend the principles of numbers but use memorized tricks to get the right answers. Although U.S. toddlers are intensely trained to count, they are quickly passed in math skills by children in places such as Asia.

**$4 BILLION**

North American educational toy market

**$2.8 BILLION**

Global education apps market for ages 0–4

**7+**

DVDs owned by the average 18-month-old

MATHIAS DARMELI *Getty Images*; SOURCES: *GLOBAL EDUCATIONAL TOYS MARKET 2017–2021*, TECHNAVIO, JULY 2017 (*markets*); "SCREEN MEDIA AND LANGUAGE DEVELOPMENT IN INFANTS AND TODDLERS: AN ECOLOGICAL PERSPECTIVE," BY DEBORAH L. LINEBARGER AND SARAH E. VAALA, IN *DEVELOPMENTAL REVIEW*, VOL. 30, NO. 2; JUNE 2010 (*DVDs*)

### GOING FOR GOLD

NOT ALL PARENTS want their little darling to win a Fields Medal for mathematics. Some prefer Olympic gold. For that result, they look to motor learning.

"If my baby walked at 10 months instead of 13 months, are they on a fast track to travel-team soccer?" asks Karen Adolph, a child psychologist at New York University. "Does speeding up motor skills have long-term effects?"

Compared with language or math skills, the motor-learning field is small, and many basic questions are still wide open. But a few insights seem clear. The first is, surprisingly, that you can supercharge your baby's ability to sit, crawl and even walk. In 1935 developmental psychologist Myrtle McGraw famously trained one baby to swim, climb and roller skate while his twin brother sat in a crib. But as soon as McGraw allowed the other brother to play as well, he quickly caught up. "Practicing motor skills accelerates motor skills in the short term," Adolph says. But there is "no evidence that it does anything for the long term."

If you want to raise the next Usain Bolt or Nolan Ryan, early walking or throwing probably will not matter. Such skills may, however, offer some cognitive advantages; kids who can sit up



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can reach for things sooner, and those who walk can explore their world earlier.

Adolph says there is another key difference between movement and cognition: the parents she meets in the laboratory are far less worked up about motor learning in their babies, which corresponds to the toy market as well. No one is selling Your Baby Can Backflip. Some products, such as little pushcarts and walkers, promise to help babies learn to walk, but the marketing statements about that seem muted and secondary to just having fun. If you give a baby a rattle, she or he will learn to shake it. Is that the first step to becoming the drummer in a Rush revival band? No.

Adolph points to running cultures such as the Tarahumara people of Mexico; they begin running at a young age, but they do not walk or crawl especially early. She is now working in Tajikistan, where babies are bound for most of the day. The practice delays when they first walk, but her early evidence shows no differences compared with how Western babies walk by preschool age.

## LEARN GRAVITY FIRST

SCIENCE-BASED INVESTIGATIONS indicate that parents cannot supercharge their babies. But that does not mean science has not generated advice for what babies should play with.

Play is incredibly important for developing minds. Just as food nourishes the body, play promotes language, cognition, spatial reasoning and other talents in ways scientists are still trying to understand. And like food, sometimes the simplest options can be the best.

For instance, blocks and Legos pop up often in the scientific literature. Kids who build stuff have better spatial reasoning and, in one controversial study, better math skills. According to experts, there is nothing magical about building; children simply benefit from toys such as balls, dump trucks and ramps that teach them about the physics of gravity, shape and movement. Watching a baby careen toward the floor or into a closed door is terrifying, but these are just their physics experiments to understand how gravity operates and whether two objects can occupy the same space.

Perhaps the most crucial experiments deal with the most enigmatic of phenomena: time. It turns out that babies do not understand time any better than they do gravity or inertia. And some experts worry that if this learning is disrupted, a skewed view can have long-lasting effects.

Dimitri Christakis is a child psychologist at the University of Washington, who directs a children's center at Seattle Children's Hospital. He studies the effect of video screen time on children, which is crucial as children increasingly use tablets, phones and laptops. He has found that it is not the screen that causes problems but the pace of the programming on it. Games and cartoons that speed up the action or quickly switch scenes may affect a child's "internal metronome," a mechanism that Christakis believes develops in the first three years to help individuals understand the pace of the world. If that pace is set too fast, it can lead to attentional problems—a theory backed by studies in which he has induced deficits in cognition and attention in mice.

Christakis compares older TV shows such as *Mister Rogers' Neighborhood* with modern, frenetic cartoons or video products for infants such as those put out in the past by a company called Baby Einstein. He is concerned that not only are TV and video games faster today but their consumers are younger. Hirsh-Pasek agrees. Her lab has also shown that no matter how interactive a game or show seems to be, it is not as beneficial as a live human being—either in person or via a video phone call. The key for nutritious play is another human who interacts at a normal pace.

Chau, the LeapFrog director, agrees that videos should not replace human interaction but says they can be a part of a child's development. Rather than playing with a real wedge or lever, a baby might do it on a screen while she is not interacting with real people.

But Christakis worries screens could have lasting detrimental effects. By looking at how parts of the brain used glutamate, a basic neurotransmitter involved in learning and memory, he has found connections to cocaine addiction in his attention-challenged mice. Overstimulation led to more enjoyment of cocaine, less sensitization to it and ever more hyperactivity. This is not to say that the same is true in humans or that overstimulated kids will turn to drugs, but addiction relies on reward networks in the brain and habit formation. To better understand these ideas, Christakis is now studying screen addiction in children as young as two years old. That would have been unheard of a decade ago, and he says he has found it in almost 10 percent of his subjects.

"My fear is that we are going to see that go up and that we'll see it start at a younger and younger age as more and more infants and toddlers spend time" on screens, Christakis says. "These devices have a lot of addictive features."

Hidden danger can lurk behind certain products, it seems. But even if educational products aimed at babies may do no harm, there is a dearth of evidence that they convey benefits in the long term. If you simply must buy some cool toy, perhaps find one that *you* want to play with. Because experts agree the time a baby spends with you—hearing you talk and watching you interact with the world—is the best education she can get.

Which brings us back to Pollak and Saffran. Standing in front of the teething ring display, they had to decide whether to try to increase their son's oral motor development. They burst out laughing and put the ring back.

"We went to the grocery store, and we bought him a package of frozen bagels for 99 cents," Pollak says. "I took one out of the freezer and let him chomp on that. It numbed his gums a little bit, and he stopped crying." SA

**Erik Vance** is a science writer and relatively new father. His first book, *Suggestible You* (National Geographic, 2016), is about how belief affects the brain.

### MORE TO EXPLORE

**Becoming Brilliant: What Science Tells Us about Raising Successful Children.** Roberta Michnick Golinkoff and Kathy Hirsh-Pasek. American Psychological Association, 2016.

**The Gardener and the Carpenter: What the New Science of Child Development Tells Us about the Relationship between Parents and Children.** Alison Gopnik. Farrar, Straus and Giroux, 2016.

Gwen Dewar's blog Parenting for the Science-Minded: www.parentingscience.com

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**DIVERGENT THINKING** may develop early in life and influence individuals' future capacity for creative thinking and a meaningful life.



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# HOW TO MEASURE THE CREATIVITY OF A ONE-YEAR-OLD

The Unusual Box test—and what it means

*By Cindi May*



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ONLINE SITES SUCH AS BUZZFEED AND PINTEREST are full of "hacks" that provide solutions to common problems by using everyday objects in uncommon ways, like protecting a razor head with a binder clip or wrapping shoes in a shower cap for travel. These ingenious ideas are the result of divergent thinking (DT)—an outside-the-box approach that generates unusual or creative alternatives to persistent challenges. DT drives adaptive innovation and is important when problems require a shift in perspective or the development of flexible, original solutions.

In laboratory studies, DT is measured with tasks that require individuals to complete picture fragments with novel drawings or to generate alternative uses for common objects (for instance, turning a paper clip into a fishing hook or an earring). Although pondering different uses for a paper clip may seem somewhat frivolous on the surface, longitudinal studies of DT suggest that children's scores on these sorts of tasks predict their personal and professional creative achievements as adults. Thus, the ability to think divergently may be established early in life and may influence people's capacity for making meaningful, influential contributions at home or work.

The potential significance of DT as an adaptive tool brings up several questions: When does this ability emerge? Is DT genetically linked, such as intelligence and other cognitive abilities? Can DT be taught or enhanced? To begin to answer these questions, a team of researchers led by Elena Hoicka, now at the University of Bristol in England, investigated DT ability in toddlers and their parents. They wanted to know whether DT can be reliably measured in children as young as one year of age and, if so, whether their DT scores were linked to those of their parents.

Because most one-year-old children cannot answer questions such as "name all the ways that you can think of to use a button," a first step in their investigation was to examine the utility of a nonverbal test of DT in one-year-old children. The Unusual Box Test (UBT) examines the ways in which a child interacts with a box that has unique features (for example, strings, ledges, a hole, stairs, rings) and five different objects (hook, spiral egg holder, feather). The UBT provides a measure of novel idea generation, with higher scores on the UBT indicating a greater number of original box-object interactions. The UBT shows good test-retest reliability in two-year-olds, and scores on the UBT correlate with scores on other standardized measures of DT in three- and four-year-old youngsters.

Hoicka and her colleagues tested a group of one-year-olds on the UBT by presenting the box on a turntable so that all its features were accessible. They then presented each of the five objects one at a time and allowed the toddlers to play. The toddlers were tested individually and, most important, were given no instructions other than to play with the box and the objects.

Researchers counted the number of unique box-object interactions that each child generated within a set time frame. The scores for the 29 toddlers ranged from 6 to 28, and those who scored high on their first interaction with the task tended to score high when they were tested again two weeks later, even when the researchers counted only brand-new box-object interactions on the second test. Thus, the consistency across tests did not reflect memory for (and repetition of) previous interactions. These data suggest that there

PRECEDING PAGES AND OPPOSITE PAGE: GETTY IMAGES



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are indeed individual differences in DT that can be measured as early as age one and that these measurements are reliable, at least over short time spans.

Children thus demonstrate an aptitude for divergent creative thought early in life, but where does this ability come from? Do toddlers with a high DT aptitude have parents with high DT? To explore this question, Hoicka's team also tested parents' DT using two different nonverbal tasks from the Thinking Creatively in Pictures Test. These tasks involved completing incomplete abstract line drawings and filling in 24 circles with pictures. Toddlers' DT scores correlated with their parents' DT scores, even when researchers controlled for the toddlers' motor-skill development. Thus, children with high DT scores tended to have parents who showed high DT.

Are genetics at play here? Maybe so. Recent research suggests that variants of specific genes may affect creativity, and therefore the correlation between toddlers' DT scores and their parents' scores could reflect the influence of these genes early in life. In addition, DT may be mediated in part by working memory, and evidence suggests there is a genetic component to working memory as well.

Don't be too concerned for your children, though, if you and your partner are not the most creative people on the planet. Other research examining creativity in twins found no differences in creativity between monozygotic and dizygotic twins, suggesting that genetic factors are only part of the answer. Social learning most likely contributes to the correlation between parent and toddler DT scores, given that toddlers are keen imitators and like to copy others. In fact, research demonstrates that children who watch someone else with high DT tend to improve their own DT scores, whereas those who are exposed to low DT behaviors reduce their own DT.

Thus, even if your child is not genetically inclined to be creative, she can learn to think outside the box by observing others. She will, however, need a creative role model. So go ahead and watch that Buzzfeed video, scroll through Pinterest or even simply go for a walk—you'll fuel not only your own creative spark but also perhaps that of your child. SA

**Cindi May** is a professor of psychology at the College of Charleston. She explores avenues for improving cognitive function in college students, older adults, and individuals with intellectual disabilities. May is also an advocate for inclusive opportunities for people with disabilities.

MORE TO EXPLORE

**Individual Differences and Age-Related Changes in Divergent Thinking in Toddlers and Preschoolers.** Simone Bijvoet-van den Berg and Elena Hoicka in *Developmental Psychology,* Vol. 50, No. 6, pages 1629–1693; March 2014.

**One-Year-Olds Think Creatively, Just Like Their Parents.** Elena Hoicka et al. in *Child Development,* Vol. 87, No. 4, pages 1099–1105; July/August 2016.

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# Building a Better Learner

## Brain studies suggest new ways to improve reading, writing and arithmetic—and even social skills

*By Gary Stix*

*Photograph by Andrew Hetherington*



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**THINKING CAP** recorded electrical signals from the brain of Elise Hardwick when she was one year old. Such work is helping to reveal how young children process sounds that form the building blocks of language.



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EIGHT-MONTH-OLD LUCAS KRONMILLER HAS JUST HAD THE SURFACE OF HIS largely hairless head fitted with a cap of 128 electrodes. A research assistant in front of him is frantically blowing bubbles to entertain him. But Lucas seems calm and content. He has, after all, come here, to the Infancy Studies Laboratory at Rutgers University, repeatedly since he was just four months old, so today is nothing unusual. He—like more than 1,000 other youngsters before him—is helping April A. Benasich and her colleagues to find out whether, even at the earliest age, it is possible to ascertain if a child will go on to experience difficulties in language that will prove a burdensome handicap when first entering elementary school.

Benasich is one of a cadre of researchers who have been employing brain-recording techniques to understand the essential processes that underlie early stages of learning. The new science of neuroeducation seeks the answers to questions that have always perplexed cognitive psychologists and pedagogues.

How, for instance, does a newborn's ability to process sounds and images relate to the child's capacity to learn letters and words a few years later? What does a youngster's ability for staying mentally focused in preschool mean for later academic success? What can educators do to foster children's social skills—also vital in the classroom? Such studies can complement the wealth of knowledge established by psychological and educational research programs.

They also promise to offer new ideas, grounded in brain science, for making better learners and for preparing babies and toddlers for reading, writing, arithmetic, and survival in the complex social network of nursery school and beyond. Much of this work focuses on the first years of life and the early grades of elementary school because some studies show that the brain is most able to change at that time.

## THE AHA! INSTANT

BENASICH STUDIES ANOMALIES in the way the brains of the youngest children perceive sound, a cognitive process fundamental to language understanding, which, in turn, forms the basis for reading and writing skills. Benasich, a former nurse, who later earned two doctorates, focuses on what she calls the aha! instant—an abrupt transition in electrical activity in the brain that signals that something new has been recognized.

Researchers at Benasich's lab in Newark, N.J., expose infants to tones of a certain frequency and duration. They then record a change in the electrical signals generated in the brain when a different frequency is played. Typically the electroencephalogram (EEG) produces a strong oscillation in response to the change—indicating that the brain essentially says, "Yes, something has changed"; a delay in the response time to the different tones means that the brain has not detected the new sound quickly enough.

The research has found that this pattern of sluggish electrical activity at six months can predict language issues at three to five years of age. Differences in activity that persist during the toddler and preschool years can foretell problems in development of the brain circuitry that processes the rapid transitions occurring during perception of the basic units of speech. If children fail to hear or process components of speech—say, a "da" or a "pa"—quickly enough as toddlers, they may lag in "sounding out" written letters or syllables in their head, which could later impede fluency in reading. These findings offer more rigorous confirmation of other research by Benasich showing that children who encounter early problems in processing these sounds test poorly on psychological tests of language eight or nine years later.

If Benasich and others can diagnose future language problems in infants, they may be able to correct them by exploiting the inherent plasticity of the developing brain—its capacity to change in response to new experiences. They may even be able to improve basic functioning for an

IN BRIEF

**The technology** and research methods of the neuroscientist have started to reveal, at the most basic level, what happens in the brain when we learn something new.
**As these studies** mature, it may become possible for a preschooler or even an infant to engage in simple exercises to ensure that the child is cognitively equipped for school.
**If successful,** such interventions could potentially have a huge effect on educational practices by dramatically reducing the incidence of various learning disabilities. But scientists, educators and parents must beware of overstated claims for brain-training methods that purport to help youngsters but have not been proved to work.



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infant whose brain is developing normally. "The easiest time to make sure that the brain is getting set up in a way that's optimal for learning may be in the first part of the first year," she says.

Games, even in the crib, could be one answer. Benasich and her team have devised a game toy that trains a baby to react to a change in tone by turning the head or shifting the eyes (detected with a tracking sensor). When the movement occurs, a video snippet plays, a reward for good effort.

In a study reported in 2014 babies who went through this training detected tiny modulations within the sounds faster and more accurately than did children who only listened passively or had no exposure to the sounds at all. Based on this research, Benasich believes that the game would assist infants impaired in processing these sounds to respond more quickly. She is now working on an interactive game that could train infants to perceive rapid sound sequences.

### THE NUMBER SENSE

FLEXING COGNITIVE MUSCLES early on may also help infants tune rudimentary math skills. Stanislas Dehaene, a neuroscientist at the French National Institute of Health and Medical Research, is a leader in the field of numerical cognition who has tried to develop ways to help children with early math difficulties. Babies have some capacity for recognizing numbers from birth. When the skill is not in place from the beginning, Dehaene says, a child may later have difficulty with arithmetic and higher math. Interventions that build this "number sense," as Dehaene calls it, may help the slow learner avoid years of difficulty in math class.

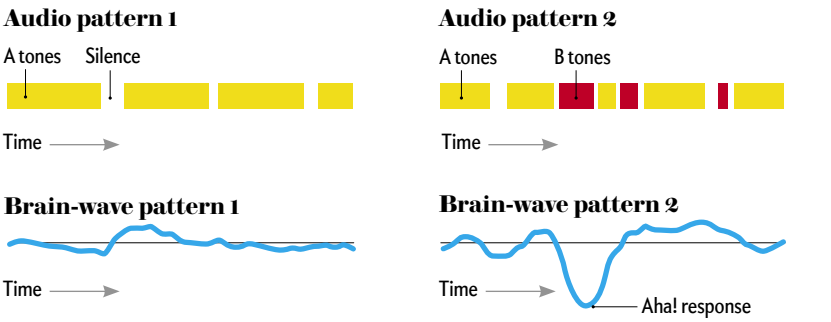
This line of research contradicts that of famed psychologist Jean Piaget, who contended that the brains of infants are blank slates, or tabula rasa, when it comes to making calculations in the crib. Children, in Piaget's view, have to develop a basic idea of what a number is from years of interacting with blocks,

## Toning Up for Language: Early Education in the Crib

Scientists at Rutgers University have developed tests to determine whether babies with normal hearing process sound optimally deep within the brain (*top panel*). They are exploring whether a game they are devising (*bottom panel*) might ready the youngest children for speaking, listening, reading and writing.

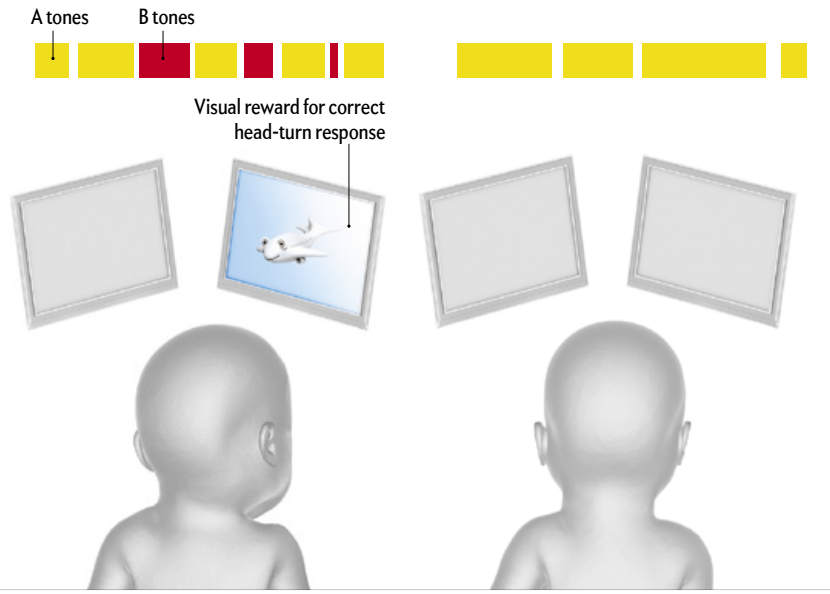
### Waiting for "Aha!"

The Infancy Studies Laboratory at Rutgers uses an electrode cap to record brain activity while babies listen to different sounds. First, they hear high-frequency tones (*labeled A*), which elicit a certain brain-wave pattern (*left*). Tones of different pitch (*labeled B*) intersperse with the initial tones and cause a temporary shift in the brain wave (the aha! response) as the brain detects the change (*right*). A slower or weaker response to this sudden change in pitch may predict language problems in later life.




### A Game for Babies

Infants at Rutgers can learn to process sound more efficiently while also having fun. A child learns to turn the head in response to the B tones (*left*) but not to the A tones (*right*) and is rewarded with a snippet of a video for a correct response. The pace of tone sequences speeds up, and the child learns to respond more and more accurately to this fast tempo.




GRAPHICS BY JEN CHRISTIANSEN; SOURCES: CYNTHIA ROESLER, APRIL A. BENASICH, TERESA REALPE AND NASEEM CHOUDHURY *Rutgers University*

*Illustration by Bryan Christie*



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Cheerios or other objects. They eventually learn that when the little oat rings get pushed around a table, the location differs, but the number stays the same.

The neuroscience community has amassed a body of research showing that humans and other animals have a basic numerical sense. Babies, of course, do not spring from the womb performing differential equations in their head. But experiments have found that toddlers will routinely reach for the row of M&Ms that has the most candies. And other research has demonstrated that even infants only a few months old comprehend relative size. If they see five objects being hidden behind a screen and then another five added to the first set, they convey surprise if they see only five when the screen is removed.

Babies also seem to be born with other innate mathematical abilities. Besides being champion estimators, they can also distinguish exact numbers—but only up to the number three or four. Dehaene was instrumental in pinpointing a brain region—a part of the parietal lobe (the intraparietal sulcus)—where numbers and approximate quantities are represented. (Put a hand on the rear portion of the top of your head to locate the parietal lobe.)

The ability to estimate group size, which also exists in dolphins, rats, pigeons, lions and monkeys, is probably an evolutionary hand-me-down that is required to gauge whether your clan should fight or flee in the face of an enemy and to ascertain which tree bears the most fruit for picking. Dehaene, along with linguist Pierre Pica of the National Center for Scientific Research in France and his colleagues, discovered more evidence for this instinctive ability through work with the Mundurukú Indians in the Brazilian Amazon, a tribe that has only an elementary lexicon for numbers. Its adult members can tell whether one array of dots is bigger than another, performing the task almost as well as a French control group did, yet most are unable to answer how many objects remain when four objects are removed from a group of six.

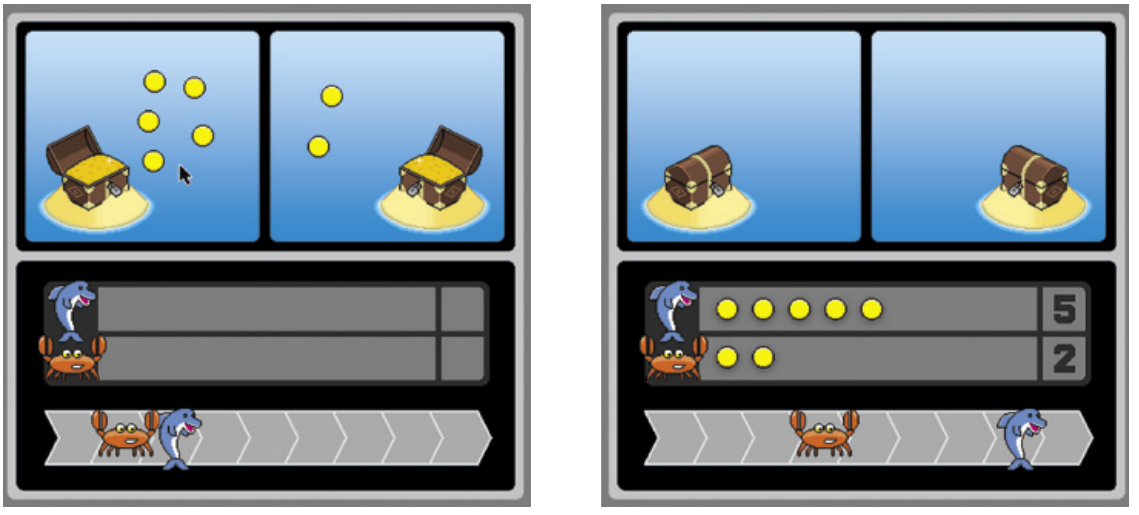
This approximation system is a cornerstone on which more sophisticated mathematics is constructed. Any deficit in these innate capacities can spell trouble later. In the early 1990s Dehaene hypothesized that children build on their internal ballpark estimation system for more sophisticated computations as they get older. Indeed, in the years since then, a number of studies have found that impaired functioning of the primitive numerical estimation system in youngsters can predict that a child will perform poorly in arithmetic and standard math achievement tests from the elementary years onward. "We realize now that the learning of a domain such as arithmetic has to be founded on certain core knowledge that is available already in infancy," Dehaene says.

It turns out that dyscalculia (the computational equivalent of dyslexia), which is marked by a lag in computational skills, affects 3 to 7 percent of children. Dyscalculia has received much less attention from educators than dyslexia has for reading—yet it may be just as crippling. "They earn less, spend less, are more likely to be sick, are more likely to be in trouble with the law, and need more help in school," notes a review article that appeared in May 2011 in *Science*.

As with language, early intervention may help. Dehaene and his team devised a simple computer game they hope will en-

## Count on It: Born to Estimate

From the time we are born, we have some concept of number. Children with deficits in this innate skill often end up struggling in later life. Stanislas Dehaene and his colleagues have created a game, the Number Race, intended to bolster our natural-born ability to estimate quantity. A preschooler judges which group of gold pieces is larger before the computer's animal avatar can steal the bigger pile (*top left*). A correct guess by the child advances his or her avatar a comparable number of spaces from its previous position; the loser moves ahead by a number equal to the smaller quantity of coins (*bottom right*). The winner is the one to reach the end of the number line first.




MODIFIED FROM "PRINCIPLES UNDERLYING THE DESIGN OF 'THE NUMBER RACE': AN ADAPTIVE COMPUTER GAME FOR REMEDIATION OF DYSCALCULIA," BY ANNA J. WILSON, STANISLAS DEHAENE, PHILIPPE PINEL, SUSANNAH K. REVKIN, LAURENT COHEN AND DAVID COHEN, IN *BEHAVIORAL AND BRAIN FUNCTIONS*, VOL. 2, 2006



*Illustration by QuickHoney*

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hance mathematical ability. Called the Number Race, it exercises these basic abilities in children aged four to eight. In one version, players must choose the larger of two quantities of gold pieces before a computer-controlled opponent steals the biggest pile. The game adapts automatically to the skill of the player, and at the higher levels the child must add or subtract gold before making a comparison to determine the biggest pile. If the child wins, he or she advances forward a number of steps equal to the gold just won. The first player to get to the last step on the virtual playing board wins.

The open-source software, which has been translated into eight languages, makes no hyperbolic claims about the benefits of brain training. Even so, more than 20,000 teachers have downloaded the software from a government-supported research institute in Finland. Dehaene's team has developed a new version of the software, called Kalulu, and is conducting a randomized trial with students in France, testing whether it prevents dyscalculia and helps healthy children bolster their basic number sense.

### GET AHOLD OF YOURSELF

THE COGNITIVE FOUNDATIONS of good learning depend heavily on what psychologists call executive function, a term encompassing such cognitive attributes as the ability to be attentive, hold what you have just seen or heard in the mental scratch pad of working memory, and delay gratification. These capabilities may predict success in school and even in the working world. In 1972 a famous experiment at Stanford University—"Here's a marshmallow, and I'll give you another if you don't eat this one until I return"—showed the importance of executive function. Children who could wait, no matter how much they wanted the treat, did better in school and later in life.

In the 21st century experts have warmed to the idea of executive function as a teachable skill. An educational curriculum called Tools of the Mind has had success in some

## 5 Common Myths about the Brain

**Some widely held ideas** about the way children learn can lead educators and parents to adopt faulty teaching principles.

| MYTH | FACT |
|---|---|
| Humans use only 10 percent of their brain | The 10 percent myth (sometimes elevated to 20) is mere urban legend, one perpetrated by the plot of the 2011 movie *Limitless,* which pivoted around a wonder drug that endowed the protagonist with prodigious memory and analytical powers. In the classroom, teachers may entreat students to try harder, but doing so will not light up "unused" neural circuits; academic achievement does not improve by simply turning up a neural volume switch. |
| "Left brain" and "right brain" people differ | The contention that we have a rational left brain and an intuitive, artistic right side is fable: humans use both hemispheres of the brain for all cognitive functions. The left brain/right brain notion originated from the realization that many (though not all) people process language more in the left hemisphere and spatial abilities and emotional expression more in the right. Psychologists have used the idea to explain distinctions between different personality types. In education, programs emerged that advocated less reliance on rational "left brain" activities. Brain-imaging studies show no evidence of the right hemisphere as a locus of creativity. And the brain recruits both left and right sides for both reading and math. |
| You must speak one language before learning another | Children who learn English at the same time as they learn French do not confuse one language with the other and so develop more slowly. This idea of interfering languages suggests that different areas of the brain compete for resources. In reality, young children who learn two languages, even at the same time, gain better generalized knowledge of language structure as a whole. |
| Brains of males and females differ in ways that dictate learning abilities | Differences do exist in the brains of males and females, and the distinctive physiology may result in differences in the way their brains function. No research, though, has demonstrated gender-specific differences in how networks of neurons become connected when we learn new skills. Even if some gender differences do eventually emerge, they will likely be small and based on averages—in other words, they will not necessarily be relevant to any given individual. |
| Each child has a particular learning style | The notion that a pupil tends to learn better by favoring a particular form of sensory input—a "visual learner" as opposed to one who listens better—has not received much validation in actual studies. For this and other myths, public perceptions appear to have outstripped the science. Uta Frith, a neuroscientist who chaired a British panel that looked at the promise of neuroeducation, urges parents and educators to tread cautiously: "There is huge demand by the general public to have information about neuroscience for education. As a consequence, there's an enormous supply of totally untested, untried and not very scientific methods." |

SOURCES: *MIND, BRAIN, AND EDUCATION SCIENCE,* BY TRACEY TOKUHAMA-ESPINOSA. W. W. NORTON, 2010; *UNDERSTANDING THE BRAIN: THE BIRTH OF A LEARNING SCIENCE.* OECD, 2007; OECD EDUCATIONAL MINISTERIAL MEETING, NOVEMBER 4–5, 2010



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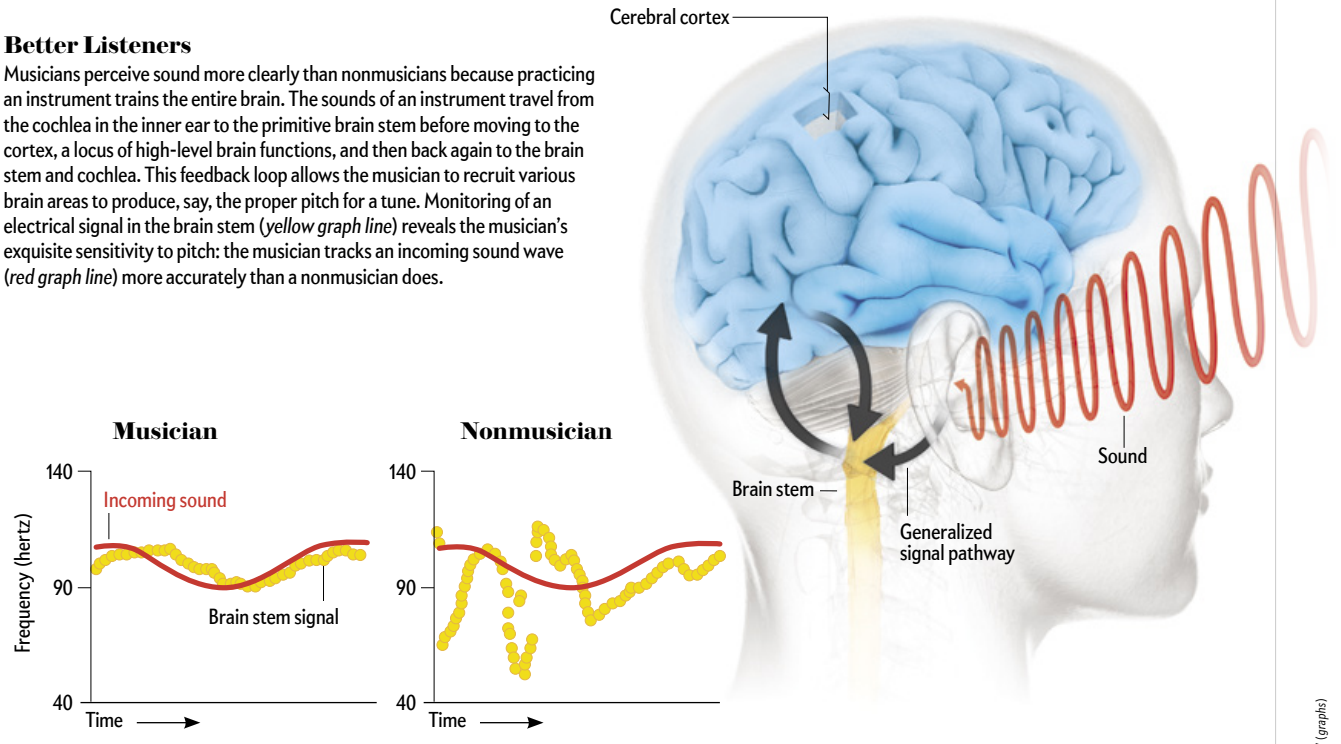
# The Best Brain Training: Practice That Violin

**Intensive musical training** from a young age fosters skills beyond just an ability to play an instrument. The musician's concentration on the fine-grained acoustics of sound helps with language comprehension and promotes cognitive skills: attention, working memory and self-regulation.

### Better Listeners

Musicians perceive sound more clearly than nonmusicians because practicing an instrument trains the entire brain. The sounds of an instrument travel from the cochlea in the inner ear to the primitive brain stem before moving to the cortex, a locus of high-level brain functions, and then back again to the brain stem and cochlea. This feedback loop allows the musician to recruit various brain areas to produce, say, the proper pitch for a tune. Monitoring of an electrical signal in the brain stem (*yellow graph line*) reveals the musician's exquisite sensitivity to pitch: the musician tracks an incoming sound wave (*red graph line*) more accurately than a nonmusician does.




low-income school districts, where children typically do not fare as well academically compared with high-income districts. The program trains children to resist temptations and distractions and to practice tasks designed to enhance working memory and flexible thinking.

In one example of a self-regulation task, a child might tell himself or herself aloud what to do. These techniques are potentially so powerful that in centers of higher learning, economists now contemplate public policy measures to improve self-control as a way to "enhance the physical and financial health of the population and reduce the rate of crime," remark the authors of a study that appeared in 2011 in the *Proceedings of the National Academy of Sciences USA*.

Findings from neuroscience labs have bolstered that view and have revealed that the tedium of practice to resist metaphorical marshmallows may not be necessary. Music training can work as well. Researchers are finding that assiduous practice of musical instruments may yield a payoff in the classroom—invoking shades of "tiger mom" author Amy Chua, who insisted that her daughters spend endless hours on the violin and piano. Playing an instrument may improve attention, working memory and self-control.

Some of the research providing such findings comes from a group of neuroscientists led by Nina Kraus of Northwestern University. Kraus, head of the Auditory Neuroscience Laboratory there, grew up with a diverse soundscape at home. Her mother, a classical musician, spoke to the future neuroscientist in her native Italian, and Kraus still plays the piano, guitar and drums. "I love it—it's a big part of my life," she says, although she considers herself "just a hack musician."

Kraus has used EEG recordings to measure how the nervous system encodes pitch, timing and timbre of musical compositions—and whether neural changes that result from practicing music improve cognitive faculties. Her lab has found that music training enhances working memory and, perhaps most important, makes students better listeners, allowing them to extract speech from the all-talking-at-once atmosphere that sometimes prevails in the classroom.

Musical training as brain tonic is still in its infancy, and a number of questions remain unanswered about exactly what type of practice enhances executive function: Does it matter whether you play the piano or guitar or whether the music was written by Mozart or Justin Bieber? Critically, will music classes help students who have learning difficulties or who

GRAPHICS BY JEN CHRISTIANSEN; SOURCE: "MUSICAL EXPERIENCE SHAPES HUMAN BRAINSTEM ENCODING OF LINGUISTIC PITCH PATTERNS," BY PATRICK C. M. WONG, ERIKA SKOE, NICOLE M. RUSSO, TASHA DEES AND NINA KRAUS, IN *NATURE NEUROSCIENCE*, VOL. 10, NO. 4, APRIL 2007 *(graphs)*



*Illustration by Bryan Christie*

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come from low-income school districts?

But Kraus points to anecdotal evidence suggesting that music training's impact extends even to academic classes. The Harmony Project provides music education to low-income youngsters in Los Angeles. Dozens of students participating in the project have graduated from high school and gone on to college, usually the first in their family to do so.

Kraus has worked with the Harmony Project and published a study in 2014 that showed that children in one of its programs who practiced a musical instrument for two years could process sounds closely linked to reading and language skills better than children who only did so for a year. Kraus is an advocate of the guitar over brain games. "If students have to choose how to spend their time between a computer game that supposedly boosts memory or a musical instrument, there's no question, in my mind, which one is more beneficial for the nervous system," Kraus says. "If you're trying to copy a guitar lead, you have to keep it in your head and try to reproduce it over and over."

## HYPE ALERT

AS RESEARCH CONTINUES on the brain mechanisms underlying success in the "four Rs"—three traditional ones (reading, writing and arithmetic) with regulation of one's impulses as the fourth—many scientists involved with neuroeducation are taking pains to avoid overhyping the interventions they are testing. They are eager to translate their findings into practical assistance for children, but they are also well aware that the research still has a long way to go. They know, too, that teachers and parents are already bombarded by a confusing raft of untested products for enhancing learning and that some highly touted tools have proved to be disappointing.

In one case in point, a small industry developed several years ago around the idea that just listening to a Mozart sonata could make a baby smarter, a contention that failed to withstand additional scrutiny. Kraus's research suggests that to gain any benefit, you have to actually play an instrument, exercising auditory-processing areas of the brain: the more you practice, the more your abilities to distinguish subtleties in sound develop. Listening alone is not sufficient.

Similarly, even some of the brain-training techniques that claim to have solid scientific proof of their effectiveness have been questioned. A meta-analysis that appeared in the March 2011 issue of the *Journal of Child Psychology and Psychiatry* reviewed studies of perhaps the best known of all brain-training methods—software called Fast ForWord, developed by Paula A. Tallal of Rutgers, Michael Merzenich of the University of California, San Francisco, and their colleagues. The analysis found no evidence of effectiveness in helping children with language or reading difficulties. As with the methods used by Benasich, a former postdoctoral fellow with Tallal, the software attempts to improve deficits in the processing of sound that can lead to learning problems. The meta-analysis provoked a sharp rebuttal from Scientific Learning, the maker of the software, which claimed that the selection criteria were too restrictive, that most studies in the analysis were poorly implemented and that the software has been improved since the studies were conducted.

The clichéd refrain—more research is needed—applies broadly to many endeavors in neuroeducation. Dehaene's number game still needs fine adjustments before it receives wide acceptance. One controlled study showed that the game helped children compare numbers, although that achievement did not carry over into better counting or arithmetic skills. The new version (Kalulu), researchers hope, will address these problems. Yet another finding has questioned whether music training improves executive function and thereby enhances intelligence.

In a nascent field, one study often contradicts another, only to be followed by a third that disputes the first two. This zigzag trajectory underlies all of science and at times leads to overreaching claims. In neuroeducation, teachers and parents have sometimes become the victims of advertising for "science-based" software and educational programs. "It's confusing. It's bewildering," says Deborah Rebhuhn, a math teacher at the Center School, a special-education institution in Highland Park, N.J., that accepts students from public schools statewide. "I don't know which thing to try. And there's not enough evidence to go to the head of the school and say that something works."

## A PRESCHOOL TUNE-UP

SCIENTISTS WHO SPEND THEIR DAYS mulling over EEG wave forms and complex digital patterns in magnetic resonance imaging realize that they cannot yet offer definitive neuroscience-based prescriptions for improving learning. The work, however, is leading to a vision of what is possible, perhaps for Generation Z or its progeny. Consider the viewpoint of John D. E. Gabrieli, a professor of neuroscience participating in a collaborative program between Harvard University and the Massachusetts Institute of Technology. In a review article in 2009 in *Science,* Gabrieli conjectured that eventually brain-based evaluation methods, combined with traditional testing, family history and perhaps genetic tests, could detect reading problems by age six and allow for intensive early intervention that might eliminate many dyslexia cases among school-aged children.

One study has already found that EEGs in kindergartners predict reading ability in fifth graders better than standard psychological measures. By undergoing brain monitoring combined with standard methods, each child might be evaluated before entering school and, if warranted, be given remedial training based on the findings that are trickling in today from neuroscience labs. If Gabrieli's vision comes to pass, brain science may imbue the notion of individualized education with a whole new meaning—one that involves enhancing the ability to learn even before a child steps foot in the classroom. SA

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### MORE TO EXPLORE

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Nina Kraus's Auditory Neuroscience Laboratory at Northwestern University: **www.brainvolts.northwestern.edu**

Watch a video of April A. Benasich's research: **ScientificAmerican.com/article/benasich-baby-brains-signal-later-language-problems**

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# RAISE A GENIUS: LESSONS FROM STUDYING SUPERSMART CHILDREN

A long-running investigation of exceptional children reveals what it takes to produce the scientists who will lead the 21st century

*By Tom Clynes*

IN BRIEF

**Precociously gifted** individuals outweigh the rest of society in their influence, and in most cases, their unique talents and abilities were recognized in their early years, nurtured and supported. **Long-term studies** of gifted students (who score in the top 1 percent on the SAT math section) go on to outperform the rest of the population in several metrics, such as income, number of patents, and number of degrees obtained. **Some research** shows positive outcomes from accelerating gifted children by skipping grades, while other studies show that merely exposing these students to advanced material can be enough to nourish their intellectual capabilities.

*Illustration by Sonia Roy*



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ON A SUMMER DAY IN 1968 PROFESSOR JULIAN STANLEY MET A BRILLIANT but bored 12-year-old named Joseph Bates. The Baltimore student was so far ahead of his classmates in mathematics that his parents had arranged for him to take a computer science course at Johns Hopkins University, where Stanley taught. Even that wasn't enough. Having leapfrogged ahead of the adults in the class, the child kept himself busy by teaching the FORTRAN programming language to graduate students.

Unsure of what to do with Bates, his computer instructor introduced him to Stanley, a researcher well known for his work in psychometrics—the study of cognitive performance. To discover more about the young prodigy's talent, Stanley gave Bates a battery of tests that included the SAT college admissions exam, usually taken by university-bound 16- to 18-year-olds in the U.S.

Bates's score was well above the threshold for admission to Johns Hopkins, which prompted Stanley to search for a local high school that would let the child take advanced mathematics and science classes. When that plan failed, Stanley convinced a dean at Johns Hopkins to let Bates, then 13, enroll as an undergraduate.

Stanley would affectionately refer to Bates as "student zero" of his Study of Mathematically Precocious Youth (SMPY), which would transform how gifted children are identified and supported by the U.S. education system. As the longest-running current longitudinal survey of intellectually talented children, SMPY has for 48 years tracked the careers and accomplishments of some 5,000 individuals, many of whom have gone on to become high-achieving scientists. The study's ever growing data set has generated more than 400 papers and several books and provided key insights into how to spot and develop talent in science, technology, engineering, mathematics (STEM) and beyond.

"What Julian wanted to know was, How do you find the kids with the highest potential for excellence in what we now call STEM, and how do you boost the chance that they'll reach that potential?" says Camilla P. Benbow, a protégé of Stanley's, who is now dean of education and human development at Vanderbilt University. But Stanley wasn't interested in just studying bright children; he wanted to nurture their intellect and enhance the odds that they would change the world. His motto, he told his graduate students, was "no more dry bones methodology."

With the first SMPY recruits now at the peak of their careers, what has become clear is how much the precociously gifted outweigh the rest of society in their influence. Many of the innovators who are advancing science, technology and culture are those whose unique cognitive abilities were identified and supported in their early years through enrichment programs such as Johns Hopkins University's Center for Talented Youth—which Stanley began in 1979 as an adjunct to SMPY. At the start, both the study and the center were open to young adolescents who scored in the top 1 percent on university entrance exams. Pioneering mathematicians Terence Tao and Lenhard Ng were 1 percenters, as were Facebook's Mark Zuckerberg, Google cofounder Sergey Brin and musician Stefani Germanotta (Lady Gaga), who all passed through the Johns Hopkins center.

"Whether we like it or not, these people really do influence our society to a great degree," says Jonathan Wai, assistant professor of education policy and psychology at the University of Arkansas. Wai combined data from 11 prospective and retrospective longitudinal studies, including SMPY, to demonstrate the correlation between early cognitive ability and adult achievement. "The kids who test in the top 1 percent tend to become our eminent scientists and academics, our Fortune 500 CEOs and federal judges, our senators and billionaires and influential journalists," he says.

Such results contradict long-established ideas suggesting that expert performance is built mainly through practice—that anyone can get to the top with enough focused effort of the right kind. SMPY, in contrast, suggests that early cognitive ability has more effect on achievement than either deliberate practice or environmental factors such as socioeconomic status. The research emphasizes the importance of nurturing precocious children, at a time when the prevailing focus in the U.S. and other countries is on improving the performance of struggling students. At the same time, the work to identify and support academically talented students has raised troubling questions about the risks of labeling children and the shortfalls of talent searches and standardized tests as a means of identifying high-



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potential students, especially in poor and rural districts.

"With so much emphasis on predicting who will rise to the top, we run the risk of selling short the many kids who are missed by these tests," says Dona Matthews, a developmental psychologist in Toronto, who co-founded the Center for Gifted Studies and Education at Hunter College. "For those children who are tested, it does them no favors to call them 'gifted' or 'ungifted.' Either way, it can really undermine a child's motivation to learn."

## START OF A STUDY

ON A MUGGY AUGUST DAY Benbow and her husband, psychologist David Lubinski, describe the origins of SMPY as they walk across the quadrangle at Vanderbilt. Benbow was a graduate student at Johns Hopkins when she met Stanley in a class he taught in 1976. Benbow and Lubinski, who have co-directed the study since Stanley's retirement, brought it to Vanderbilt in 1998.

"In a sense, that brought Julian's research full circle, since this is where he started his career as a professor," Benbow says as she nears the university's psychology laboratory, the first U.S. building dedicated to the study of the field. Built in 1915, it houses a small collection of antique calculators—the tools of quantitative psychology in the early 1950s, when Stanley began his academic work in psychometrics and statistics.

His interest in developing scientific talent had been piqued by one of the most famous longitudinal studies in psychology, Lewis Terman's Genetic Studies of Genius. Beginning in 1921, Terman selected teenage subjects on the basis of high IQ scores, then tracked and encouraged their careers. But to Terman's chagrin, his cohort produced only a few esteemed scientists. Among those rejected because their IQ of 129 was too low to make the cut was William Shockley, the Nobel Prize–winning co-inventor of the transistor. Physicist Luis Alvarez, another Nobel winner, was also rejected.

Stanley suspected that Terman wouldn't have missed Shockley and Alvarez if he'd had a reliable way to test them specifically on quantitative reasoning ability. So Stanley decided to try the Scholastic Aptitude Test (now simply the SAT). Although the test is intended for older students, Stanley hypothesized that it would be well suited to measuring the analytical reasoning abilities of elite younger students.

In March 1972 Stanley rounded up 450 bright 12- to 14-year-olds from the Baltimore area and gave them the mathematics portion of the SAT. It was the first standardized academic "talent search." (Later, researchers included the verbal portion and other assessments.)

"The first big surprise was how many adolescents could figure out math problems that they hadn't encountered in their course work," says developmental psychologist Daniel Keating, then a Ph.D. student at Johns Hopkins. "The second surprise was how many of these young kids scored well above the admissions cut-off for many elite universities."

Stanley hadn't envisioned SMPY as a multidecade longitudinal study. But after the first follow-up survey, five years later, Benbow proposed extending the study to track subjects through their lives, adding cohorts and including assessments of interests, preferences, and occupational and other life accomplishments. The study's first four cohorts range from the top 3 percent to the top 0.01 percent in their SAT scores. The SMPY team added a fifth cohort of the leading mathematics and science graduate students in 1992 to test the generalizability of the talent search model for identifying scientific potential.

"I don't know of any other study in the world that has given us such a comprehensive look at exactly how and why STEM talent develops," says Christoph Perleth, a psychologist at the University of Rostock in Germany, who studies intelligence and talent development.

## SPATIAL SKILLS

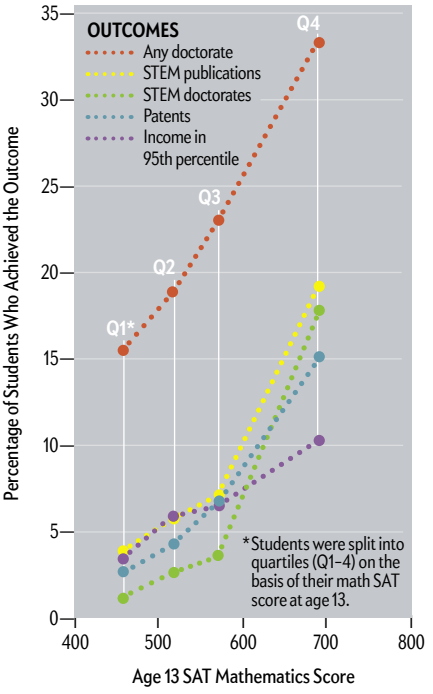
AS THE DATA FLOWED IN, it quickly became apparent that a one-size-fits-all approach to gifted education and to education in general was inadequate.

"SMPY gave us the first large-sample basis for the field to move away from general intelligence toward assessments of specific cognitive abilities, interests and other factors," says Rena Subotnik, who directs the Center for Gifted Education Policy at the American Psychological Association in Washington, D.C.

In 1976 Stanley started to test his second cohort (a sample of 563 13-year-olds who scored in the top 0.5 percent on the SAT) on spatial ability—the capacity to understand and remember spatial relations between objects. Tests for spatial ability might include matching objects that are seen from different perspectives, determining which cross section will result when an object is cut in certain ways or estimating water levels on tilted bottles of various shapes. Stanley was curious about whether spatial ability might better predict educational and occupational outcomes than could measures of quantitative and verbal reasoning on their own.

## Top of the Charts

**Long-term studies** of gifted students—those who scored in the top 1 percent as young adolescents on the math section of the SAT—reveal that the highest scorers (*upper quartile*) went on to outperform the rest by several measures.




SOURCES: "HOW TO RAISE A GENIUS: LESSONS FROM A 45-YEAR STUDY OF SUPER-SMART CHILDREN," BY TOM CLYNES, IN *NATURE*, VOL. 537; SEPTEMBER 8, 2016; "BEYOND THE THRESHOLD HYPOTHESIS: EVEN AMONG THE GIFTED AND TOP MATH/SCIENCE GRADUATE STUDENTS, COGNITIVE ABILITIES, VOCATIONAL INTERESTS, AND LIFESTYLE PREFERENCES MATTER FOR CAREER CHOICE, PERFORMANCE, AND PERSISTENCE," BY KIMBERLEY FERRIMAN ROBERTSON ET AL., IN *CURRENT DIRECTIONS IN PSYCHOLOGICAL SCIENCE*, VOL. 19, NO. 6; DECEMBER 2010



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**SUMMER ENRICHMENT:** Fifth and sixth graders collaborate on a health research project at a Duke Talent Identification Program at Southwestern University in Texas (*1*). Middle and high school students count bacteria in a petri dish for a genetics course at the Johns Hopkins Center for Talented Youth (*2*).

Follow-up surveys—at ages 18, 23, 33 and 48—backed up his hunch. A 2013 analysis found a correlation between the number of patents and peer-refereed publications that people had produced and their earlier scores on SATs and spatial ability tests. The SAT tests jointly accounted for about 11 percent of the variance; spatial ability accounted for an additional 7.6 percent.

The findings, which dovetail with those of other recent studies, suggest that spatial ability plays a major part in creativity and technical innovation. "I think it may be the largest known untapped source of human potential," says Lubinski, who adds that students who are only marginally impressive in mathematics or verbal ability but high in spatial ability often make exceptional engineers, architects and surgeons. "And yet no admissions directors I know of are looking at this, and it's generally overlooked in school-based assessments."

Although studies such as SMPY have given educators the ability to identify and support gifted youngsters, worldwide interest in this population is uneven. In the Middle East and East Asia, high-performing STEM students have received significant attention over the past decade. South Korea, Hong Kong and Singapore screen children for giftedness and steer high performers into innovative programs. In 2010 China launched a 10-year National Talent Development Plan to support and guide top students into science, technology and other high-demand fields.

In Europe, support for research and educational programs for gifted children has ebbed, as the focus has moved more toward inclusion. England decided in 2010 to scrap the National Academy for Gifted and Talented Youth and redirected funds toward an effort to get more poor students into leading universities.

## ON THE FAST TRACK

WHEN STANLEY BEGAN HIS WORK, the choices for bright children in the U.S. were limited, so he sought out environments in which early talent could blossom. "It was clear to Julian that it's not enough to identify potential; it has to be developed in appropriate ways if you're going to keep that flame well lit," says Linda Brody, who studied with Stanley and now runs a program at Johns Hopkins focused on counseling profoundly gifted children.

At first, the efforts were on a case-by-case basis. Parents of other bright children began to approach Stanley after hearing about his work with Bates, who thrived after entering university. By 17, he had earned bachelor's and master's degrees in computer science and was pursuing a doctorate at Cornell University. Later, as a professor at Carnegie Mellon University, he would become a pioneer in artificial intelligence.

"I was shy, and the social pressures of high school wouldn't have made it a good fit for me," says Bates, now 60. "But at college, with the other science and math nerds, I fit right in, even though I was much younger. I could grow up on the social side at my own rate and also on the intellectual side because the faster pace kept me interested in the content."

The SMPY data supported the idea of accelerating fast learners by allowing them to skip school grades. In a comparison of children who bypassed a grade with a control group of similarly smart children who didn't, the grade skippers were 60 percent more likely to earn doctorates or patents and more than twice as likely to get a Ph.D. in a STEM field. Acceleration is common in SMPY's elite 1-in-10,000 cohort, whose intellectual diversity and rapid pace of learning make them among the most challenging to educate. Advancing these students costs little or nothing, and in some cases may save schools money: "These kids often don't need anything innovative or novel," Lubinski says. "They just need earlier access to what's already available to older kids."

Many educators and parents continue to believe that acceleration is bad for children—that it will hurt them socially, push them out of childhood or create knowledge gaps. But education researchers generally agree that acceleration should be much more frequently considered for kids who are advanced relative to their age peers. When carefully applied, with the necessary supports for children and their teachers, acceleration is usually beneficial socially and emotionally, as well as academically and professionally.

Skipping grades is not the only option. SMPY researchers say that even modest interventions—for example, access to challenging material such as college-level Advanced Placement courses—have a demonstrable effect. Among students with high ability, those who were given a richer density of advanced precollegiate educational opportunities in STEM went on to pub-

IVAN ROSS *Duke Talent Identification Program (1);* JOHNS HOPKINS CENTER FOR TALENTED YOUTH *(2)*



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lish more academic papers, earn more patents and pursue higher-level careers than their equally smart peers who didn't have these opportunities.

Despite SMPY's many insights, researchers still have an incomplete picture of giftedness and achievement. "We don't know why, even at the high end, some people will do well and others won't," says Douglas Detterman, a psychologist who studies cognitive ability at Case Western Reserve University. "Intelligence won't account for all the differences between people; motivation, personality factors, how hard you work and other things are important."

Some insights have come from German studies that have a methodology similar to SMPY's. The Munich Longitudinal Study of Giftedness, which started tracking 26,000 gifted students in the mid-1980s, found that cognitive factors were the most predictive but that some personal traits—such as motivation, curiosity and ability to cope with stress—had a limited influence on performance. Environmental factors, such as family, school and peers, also had an impact.

The data from such intellectual talent searches also contribute to knowledge of how people develop expertise in subjects. Some researchers and writers, notably psychologist Anders Ericsson of Florida State University and author Malcolm Gladwell, have popularized the idea of an ability threshold. This holds that for individuals beyond a certain IQ barrier (120 is often cited), concentrated practice time is much more important than additional intellectual abilities in acquiring expertise. But data from SMPY and the Duke talent program dispute that hypothesis. A study published in 2018 compared the outcomes of students in the top 1 percent of childhood intellectual ability with those in the top 0.01 percent. Whereas the first group gain advanced degrees at about 25 times the rate of the general population, the more elite students earn Ph.D.s at about 50 times the base rate.

But some of the work is controversial. In North America and Europe, some child development experts lament that much of the research on talent development is driven by the urge to predict who will rise to the top, and educators have expressed considerable unease about the concept of identifying and labeling a group of pupils as gifted or talented.

"A high test score tells you only that a person has high ability and is a good match for that particular test at that point in time. A low test score tells you practically nothing," Matthews says, because many factors can depress students' performance, including their cultural backgrounds and how comfortable they are with taking high-stakes tests. Matthews contends that when children who are near the high and low extremes of early achievement feel assessed in terms of future success, it can damage their motivation to learn and can contribute to what Stanford University psychologist Carol S. Dweck calls a fixed mindset. It's far better, Dweck says, to encourage a growth mindset, in which children believe that brains and talent are merely a starting point and that abilities can be developed through hard work and continued intellectual risk-taking.

"Students focus on improvement instead of worrying about how smart they are and hungering for approval," Dweck says. "They work hard to learn more and get smarter." Research by Dweck and her colleagues shows that students who learn with this mindset show greater motivation at school, get better marks and have higher test scores.

Benbow agrees that standardized tests should not be used to limit students' options but rather to develop learning and teaching strategies appropriate to children's abilities, which allow students at every level to reach their potential.

Benbow and Lubinski recently conducted a midlife survey of the profoundly gifted cohort (the 1 in 10,000), with an emphasis on career achievements and life satisfaction, and resurveyed their 1992 sample of graduate students at leading U.S. universities. The forthcoming papers may further erode the enduring misperception that gifted children are bright enough to succeed on their own, without much help.

"The education community is still resistant to this message," says David Geary, a cognitive developmental psychologist at the University of Missouri–Columbia, who specializes in math learning. "There's a general belief that kids who have advantages, cognitive or otherwise, shouldn't be given extra encouragement. That we should focus more on lower-performing kids." Although gifted education specialists herald the expansion of talent development options in the U.S., the benefits have mostly been limited so far to students who are at the top of both the talent and socioeconomic curves.

"We know how to identify these kids, and we know how to help them," Lubinski says. "And yet we're missing a lot of the smartest kids in the country."

As Lubinski and Benbow walk through the quadrangle, the clock strikes noon, releasing packs of enthusiastic adolescents racing toward the dining hall. Many are participants in the Vanderbilt Programs for Talented Youth, summer enrichment courses in which gifted students spend three weeks gorging themselves on a year's worth of mathematics, science or literature. Others are participants in Vanderbilt's sports camps.

"They're just developing different talents," says Lubinski, a former high school and college wrestler. "But our society has been much more encouraging of athletic talents than we are of intellectual talents."

Yet these gifted students, the "mathletes" of the world, can shape the future. "When you look at the issues facing society—whether it's health care, climate change, terrorism, energy—these are the kids who have the most potential to solve these problems," Lubinski says. "These are the kids we'd do well to bet on." SA

**Tom Clynes** is an author and photojournalist whose work has appeared in *National Geographic*, *Nature*, the *New York Times* and many other publications. His most recent book is *The Boy Who Played with Fusion: Extreme Science, Extreme Parenting, and How to Make a Star* (Houghton Mifflin Harcourt, 2015).

## MORE TO EXPLORE

**Experts Are Born, Then Made: Combining Prospective and Retrospective Longitudinal Data Shows That Cognitive Ability Matters.** Jonathan Wai in *Intelligence,* Vol. 45, pages 74–80; July–August 2014.

**Life Paths and Accomplishments of Mathematically Precocious Males and Females Four Decades Later.** David Lubinski, Camilla P. Benbow and Harrison J. Kell in *Psychological Science,* Vol. 25, No. 12, pages 2217–2232; December 2014.

**When Lightning Strikes Twice: Profoundly Gifted, Profoundly Accomplished.** Matthew C. Makel, Harrison J. Kell, David Lubinski, Martha Putallaz and Camilla P. Benbow in *Psychological Science,* Vol. 27, No. 7, pages 1004–1018; July 2016.

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# Can We Keep Getting Smarter?

Ever rising IQ scores suggest that future generations will make us seem like dimwits in comparison

*By Tim Folger*

THIRTY YEARS AGO JAMES R. FLYNN, a researcher at the University of Otago in New Zealand, discovered a phenomenon that social scientists still struggle to explain: IQ scores have been increasing steadily since the beginning of the 20th century. Flynn went on to examine intelligence-test data from more than two dozen countries and found that scores were rising by 0.3 point a year—three full points per decade. Nearly three decades of follow-up studies have confirmed the statistical reality of the global uptick, now known as the Flynn effect. And scores are still climbing.

PHOTOGRAPH BY KEVIN VAN AELST



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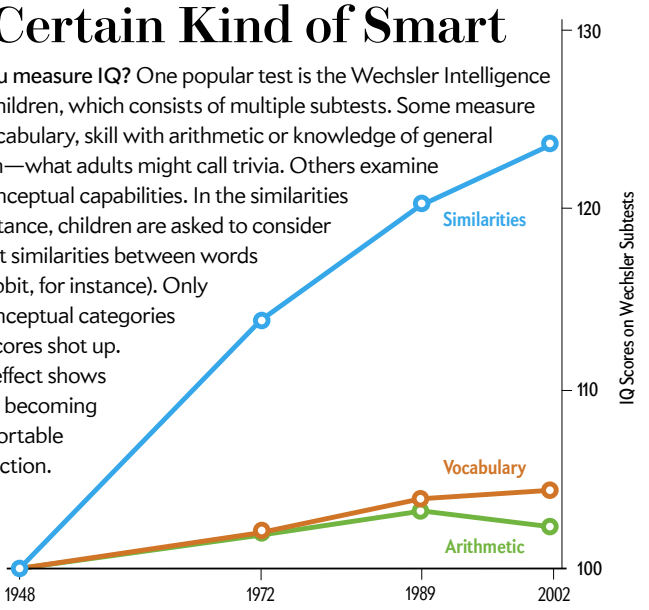
"To my amazement, in the 21st century the increases are continuing," says Flynn, whose book on the subject—*Are We Getting Smarter?*—was published in 2012. "The latest data show the gains in America humming right along at the old rate of three tenths of a point a year."

One of the strangest aspects of the Flynn effect is its relentless monotony—it does not slow or stop and restart. It just moves steadily upward, "as if guided by an invisible hand," Flynn says. Joseph Rodgers, a psychologist now at Vanderbilt University, examined the test results of nearly 13,000 American students to see if he could detect the Flynn effect on more granular timescales. "We wondered if the students' scores would get better over a five- or 10-year period. Well, they get better over a one-year period," Rodgers says. "The increase is there, systematically, year by year by year. Kids born in 1989 do a little better than kids born in 1988."

The Flynn effect means that children will, on average, score about 10 points higher on IQ tests than their parents did. By the end of this century our descendants will have nearly a 30-point advantage over us—the difference between average intelligence and the top 2 percent of the population—*if* the Flynn effect continues. But can it continue? Will the trend go on indefinitely, leading to a future filled with people who would be considered geniuses by today's standards? Or is there some natural limit to the Flynn effect and to human intelligence?

## A Certain Kind of Smart

**How do you measure IQ?** One popular test is the Wechsler Intelligence Scale for Children, which consists of multiple subtests. Some measure a child's vocabulary, skill with arithmetic or knowledge of general information—what adults might call trivia. Others examine a child's conceptual capabilities. In the similarities test, for instance, children are asked to consider the abstract similarities between words (fox and rabbit, for instance). Only in these conceptual categories have test scores shot up. The Flynn effect shows that we are becoming more comfortable with abstraction.




### THE MODERN MIND

ALMOST AS SOON AS researchers recognized the Flynn effect, they saw that the ascending IQ scores were the result almost entirely of improved performances on specific parts of the most widely used intelligence tests. One such test, the Wechsler Intelligence Scale for Children, or WISC, has multiple sections, each of which assesses different skills. It would seem more natural to expect improvements in crystallized intelligence—the kind of knowledge picked up in school. That is not happening: scores in the sections that measure skills in arithmetic and vocabulary levels have remained largely constant over time.

Most of the IQ gains come from just two subtests devoted to abstract reasoning [*see box above*]. One deals with "similarities" and poses questions such as "How are an apple and an orange alike?" A low-scoring answer would be "They're both edible." A higher-scoring response would be "They're both fruit," an answer that transcends simple physical qualities. The other subtest consists of a series of geometric patterns that are related in some abstract way, and the test taker must correctly identify the relation among the patterns.

A paradox of the Flynn effect is that tests such as these were designed to be completely nonverbal and culture-free measurements of what psychologists call fluid intelligence—an innate capacity to solve unfamiliar problems. Yet the Flynn effect clearly shows that something in the environment is having a marked influence on the supposedly culture-free components of intelligence in populations the world over. Psychologists Ainsley Mitchum of Florida State University and Mark Fox, then at the University of Richmond, who have made detailed studies of generational differences in performance on intelligence tests, suspect that our enhanced ability to think abstractly may be linked to a new flexibility in the way we perceive objects in the world.

"Everybody is familiar with the start 'button' on a computer screen, but it's not really a button," Mitchum says. "I was trying to explain to my grandmother how to turn her computer off, and I said, 'Well, you hit the start button and select shutdown.' She was banging the mouse on the screen."

Mitchum adds that his grandmother is not unintelligent. She did, however, grow up in a world where buttons were buttons, and phones certainly were not cameras. Many researchers, Flynn among them, argue that rising IQ scores do not reflect an increase in our raw brainpower. Rather the Flynn effect shows how *modern* our minds have become. Such tests require a facility with recognizing abstract categories and making connections among them. And that facility, Flynn says, has

IN BRIEF

**IQ scores** have been steadily rising for a century, a phenomenon now known as the Flynn effect. **The surge in scores** comes from supposedly "culture-free" tests of intelligence such as pattern matching. **Researchers believe** the effect has its root in the increasingly abstracted nature of modern life. **More advanced minds** create technologies that, in turn, enhance intelligence still further, forging a feedback loop that shows no signs of abating.

SOURCE: *ARE WE GETTING SMARTER? RISING IQ IN THE TWENTY-FIRST CENTURY*, BY JAMES R. FLYNN. CAMBRIDGE UNIVERSITY PRESS, 2012



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become more useful over the past century than at any previous time in human history.

"If you don't classify abstractions, if you're not used to using logic, you can't really master the modern world," Flynn says. "Alexander Luria, a Soviet psychologist, did some wonderful interviews with peasants in rural Russia in the 1920s. He would say to them, 'Where there is always snow, bears are always white. There is always snow at the North Pole. What color are the bears there?' They would say they had never seen anything but brown bears. They didn't think of a hypothetical question as meaningful."

The peasants were not stupid. Their world just required different skills. "I think the most fascinating aspect of this isn't that we do so much better on IQ tests," Flynn says. "It's the new light it sheds on what I call the history of the mind in the 20th century."

A naive interpretation of the Flynn effect quickly leads to some strange conclusions. Simply extrapolating the effect back in time, for example, would suggest that the average person in Great Britain in 1900 would have had an IQ of around 70 by 1990 standards. "That would mean that the average Brit was borderline mentally retarded and wouldn't have been able to follow the rules of cricket," says David Hambrick, a cognitive psychologist at Michigan State University. "And of course, that's absurd."

We may not be smarter than our forebears, but there is no doubt our minds have changed. Flynn believes the change began with the industrial revolution, which engendered mass education, smaller families, and a society in which technical and managerial jobs replaced agricultural ones. New professional classes emerged—engineers, electricians, industrial architects—and their positions demanded a mastery of abstract principles. Education, in turn, became the driver for still more innovation and social change, setting up an ongoing positive feedback loop.

Most researchers agree with Flynn's broad assessment that the industrial revolution and technological advances are responsible for his eponymous effect. Yet pinning down precise causes—which might allow for the design of educational or social policies to augment the effect—has been difficult. Improvements in education certainly account for part of the advances. As recently as the beginning of the 20th century, most Americans spent no more than seven years in school. Today about half of all adults have had at least some tertiary education.

Formal education, though, cannot entirely explain what is going on. Some researchers had assumed that most of the IQ increases seen over the 20th century might have been driven by gains at the left end of the intelligence bell curve among those with the lowest scores, an outcome that would likely be a consequence of better educational opportunities. A 2011 study by Jonathan Wai, now at the University of Arkansas, and Martha Putallaz of Duke University, however, looked at 20 years of data that comprise 1.7 million test results of fifth, sixth and seventh graders and found that the scores of the top 5 percent of the students were going up in perfect lockstep with the Flynn effect. Wai and Putallaz's results suggest that because the entire intelligence curve is shifting, the cultural forces behind the increase must be influencing everyone equally. The researchers speculate that the ubiquity of sophisticated video games—and even some television shows—may provide a training ground that enhances the problem-solving skills needed for IQ tests.

For Rodgers, the universality of the Flynn effect confirms the pointlessness of seeking a single cause: "There must be four or five dominant causes, any one of which can stand against fluxes or wanes in the other." Improved childhood nutrition, universal education and smaller families are some of the most likely causes. In a 2017 study, Rodgers and his graduate student Patrick O'Keefe identified the role of highly educated mothers as another potentially important factor. "As long as two causes were in existence, even when something like the Second World War came along and caused the other two to disappear, the Flynn effect kept cranking along," Rodgers says.

## MENTAL EVOLUTION

WILL IQ SCORES KEEP GOING UP? One thing we can be sure of is that the world around us will continue to change, largely because of our own actions.

Flynn likes to use a technological analogy to describe the long-term interaction between mind and culture. "The speeds of automobiles in 1900 were absurdly slow because the roads were so lousy," he says. "You would have shaken yourself to pieces." But roads and cars co-evolved. When roads improved, cars did, too, and improved roads prompted engineers to design even faster cars.

Our minds and culture are locked in a similar feedback loop. We are creating a world where information takes forms and moves with speeds unimaginable just a few decades ago. Every gain in technology demands minds capable of accommodating the change, and the changed mind reshapes the world even more. The Flynn effect is unlikely to end during this century, presaging a future world where you and I would be considered woefully premodern and literal.

Of course, our minds are not only changing in ways that can be captured by IQ tests. "People are getting faster—I'm certain of this," Hambrick says. "A common practice in reaction-time research is to discard responses that are below about 200 milliseconds. It had been thought that 200 milliseconds is about the fastest that people can respond. But if you ask someone who has done this sort of research, they're having to discard more trials; people are getting faster. We text, we play video games, we do a lot more things that require really fast responses. I think once we have enough data, we'll be able to see a Flynn-like effect on measures of perceptual speed."

Maybe we should not be so surprised by the existence of something like the Flynn effect. Its absence would be more startling; it would mean we were no longer responding to the world we are creating. The Flynn effect itself is neither good nor bad—it is a symptom of our adaptability. If we are lucky, perhaps we will keep building a world that will make us smarter and smarter—one where our descendants will marvel at our simplicity. SA

**Tim Folger** is an award-winning science writer and editor of *The Best American Science* and *Nature Writing* series of books.

MORE TO EXPLORE

**Does Your Family Make You Smarter? Nature, Nurture, and Human Autonomy.** James R. Flynn. Cambridge University Press, 2016.

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# MAKING AI MORE HUMAN

*Illustration by Simon Prades*

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# Artificial intelligence has staged a revival by starting to incorporate what we know about how children learn

*By Alison Gopnik*

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IF YOU SPEND MUCH TIME WITH CHILDREN, YOU'RE BOUND TO WONDER HOW young human beings can possibly learn so much so quickly. Philosophers, going all the way back to Plato, have wondered, too, but they've never found a satisfying answer. My five-year-old grandson, Augie, has learned about plants, animals and clocks, not to mention dinosaurs and spaceships. He also can figure out what other people want and how they think and feel. He can use that knowledge to classify what he sees and hears and make new predictions. He has proclaimed, for example, that a recently discovered species of titanosaur on display at the American Museum of Natural History in New York City is a plant eater, so that means it really isn't that scary.

Yet all that reaches Augie from his environment is a stream of photons hitting his retina and disturbances of air contacting his eardrums. The neural computer that sits behind his blue eyes manages somehow to start with that limited information from his senses and to end up making predictions about plant-eating titanosaurs. One lingering question is whether electronic computers can do the same.

During the past 15 years or so computer scientists and psychologists have been trying to find an answer. Children acquire a great deal of knowledge with little input from teachers or parents. Despite enormous strides in machine intelligence, even the most powerful computers still cannot learn as well as a five-year-old does.

Figuring out how the child brain actually functions—and then creating a digital version that will work as effectively—will challenge computer scientists for decades to come. But in the meantime, they are beginning to develop artificial intelligence that incorporates some of what we know about how humans learn.

## THIS WAY UP

AFTER THE FIRST BURST of enthusiasm in the 1950s and 1960s, the quest for AI languished for decades. In the past few years, though, there have been striking advances, especially in the field of machine learning, and AI has become one of the hottest developments in technology. Many utopian or apocalyptic predictions have emerged about what those advances mean. They have, quite literally, been taken to presage either immortality or the end of the world, and a lot has been written about both these possibilities.

I suspect that developments in AI lead to such strong feelings because of our deep-seated fear of the almost human. The idea that creatures might bridge the gap between the human and the artificial has always been deeply disturbing, from the medieval golem to Frankenstein's monster to Ava, the sexy robot fatale in the movie *Ex Machina*.

But do computers really learn as well as humans? How much of the heated rhetoric points to revolutionary change, and how much is just hype? The details of how computers learn to recognize, say, a cat, a spoken word or a Japanese character can be hard to follow. But on closer inspection, the basic ideas behind machine learning are not as baffling as they first seem.

One approach tries to solve the problem by starting with the stream of photons and air vibrations that Augie, and all of us, receives—and that reaches the computer as pixels of a digital image and sound samples of an audio recording. It then tries to extract a series of patterns in the digital data that can detect and identify whole objects in the surrounding world. This so-called bottom-up approach has roots in the ideas of philosophers such as David Hume and John Stuart Mill and psychologists such as Ivan Pavlov and B. F. Skinner, among others.

In the 1980s scientists figured out a compelling and ingenious way to apply bottom-up methods to let computers hunt for meaningful patterns in data. "Connectionist," or "neural network," systems take inspiration from the way that neurons convert light patterns at your retina into representations of the

IN BRIEF

**How do young children** know what they know? That question has long preoccupied philosophers and psychologists—and now computer scientists.

**Specialists in artificial intelligence** are studying the mental reasoning powers of preschoolers to develop ways to teach machines about the world.

**Two rival** machine-learning strategies—both halting attempts to mimic what children do naturally—have begun to transform AI as a discipline.



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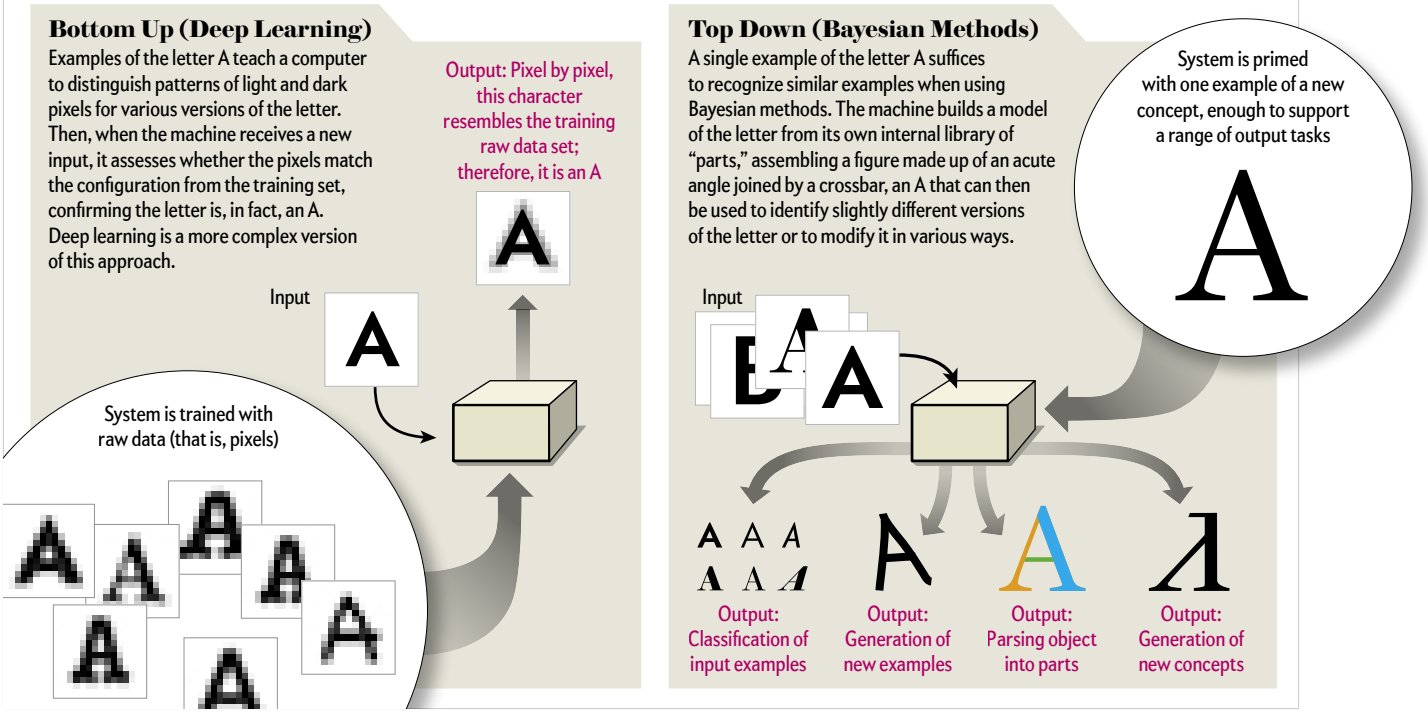
# Two Paths to AI's Resurgence

**Problems the average five-year-old solves** readily can stump even the most powerful computers. AI has made a spirited comeback in recent years by teaching computers to learn about the world somewhat like a child does. The machine recognizes the letter "A" either from raw sensory information—a bottom-up approach—or by making a guess from preexisting knowledge—a top-down approach.


Bottom Up (Deep Learning)
Examples of the letter A teach a computer to distinguish patterns of light and dark pixels for various versions of the letter. Then, when the machine receives a new input, it assesses whether the pixels match the configuration from the training set, confirming the letter is, in fact, an A. Deep learning is a more complex version of this approach.
Output: Pixel by pixel, this character resembles the training raw data set; therefore, it is an A
Input
System is trained with raw data (that is, pixels)
Top Down (Bayesian Methods)
A single example of the letter A suffices to recognize similar examples when using Bayesian methods. The machine builds a model of the letter from its own internal library of "parts," assembling a figure made up of an acute angle joined by a crossbar, an A that can then be used to identify slightly different versions of the letter or to modify it in various ways.
System is primed with one example of a new concept, enough to support a range of output tasks
Input
Output: Classification of input examples
Output: Generation of new examples
Output: Parsing object into parts
Output: Generation of new concepts

world around you. A neural network does something similar. It uses interconnected processing elements, akin to biological cells, to transform pixels at one layer of the network into increasingly abstract representations—a nose or an entire face—as data are crunched at progressively higher layers.

Neural-network ideas have gone through a recent revival because of new techniques called deep learning—technology now being commercialized by Google, Facebook and other tech giants. The ever increasing power of computers—the exponential increase in computing capability that is captured by what is known as Moore's law—also has a part in the new success of these systems. So does the development of enormously large data sets. With better processing capabilities and more data to crunch, connectionist systems can learn far more effectively than we might have once thought.

Over the years the AI community has seesawed between favoring these kinds of bottom-up solutions to machine learning and alternative top-down approaches. Top-down approaches leverage what a system already knows to help it learn something new. Plato, as well as so-called rationalist philosophers such as René Descartes, believed in a top-down approach to learning—and it played a big role in early AI. In the 2000s such methods also experienced their own rebirth in the form of probabilistic, or Bayesian, modeling.

Like scientists, top-down systems start out by formulating abstract and wide-ranging hypotheses about the world. The systems then make predictions about what the data should look like if those hypotheses are correct. Also like scientists, the systems then revise their hypotheses, depending on the outcome of those predictions.

## NIGERIA, VIAGRA AND SPAM

BOTTOM-UP METHODS are perhaps the most readily understood, so let's consider them first. Imagine that you are trying to get your computer to separate important messages from the spam that arrives in your in-box. You might notice that spam tends to have certain distinguishing characteristics: a long list of recipient addressees, an originating address in Nigeria or Bulgaria, references to $1-million prizes or perhaps mention of Viagra. But perfectly useful messages might look the same. You don't want to miss the announcement that you have earned a promotion or an academic award.

If you compare enough examples of spam against other types of e-mails, you might notice that only the spam tends to have qualities that combine in certain telltale ways—Nigeria, for instance, plus a promise of a $1-million prize together spell trouble. In fact, there might be some quite subtle higher-level patterns that discriminate between the spam messages and the useful ones—misspellings and IP addresses that are not at all obvious, for example. If you could detect them, you could accurately filter out the spam—without fear of missing a notice that your Viagra has shipped.

Bottom-up machine learning can ferret out the relevant

SOURCE: "HUMAN-LEVEL CONCEPT LEARNING THROUGH PROBABILISTIC PROGRAM INDUCTION," BY BRENDEN M. LAKE, RUSLAN SALAKHUTDINOV AND JOSHUA B. TENENBAUM, IN *SCIENCE*, VOL. 350; DECEMBER 11, 2015 (*Bayesian example*)

*Illustration by Jen Christiansen*



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clues to solve this kind of task. To do this, a neural network must go through its own learning process. It evaluates millions of examples from huge databases, each labeled as spam or as an authentic e-mail. The computer then extracts a set of identifying features that separate spam from everything else.

In a similar way, the network might inspect Internet images labeled "cat," "house," "stegosaurus," and so on. By extracting the common features in each set of images—the pattern that distinguishes all the cats from all the dogs—it can identify new images of a cat, even if it has never seen those particular images before.

One bottom-up method, called unsupervised learning, is still in its relative infancy, but it can detect patterns in data that have no labels at all. It simply looks for clusters of features that identify an object—noses and eyes, for example, always go together to form a face and differ from the trees and mountains in the background. Identifying an object in these advanced deep-learning networks takes place through a division of labor in which recognition tasks are apportioned among different layers of the network.

A 2015 article in *Nature* demonstrated just how far bottom-up methods have come. Researchers at DeepMind, a company owned by Google, used a combination of two different bottom-up techniques—deep learning and reinforcement learning—in a way that enabled a computer to master Atari 2600 video games. The computer began knowing nothing about how the games worked. At first, it made random guesses about the best moves while receiving constant feedback about its performance. Deep learning helped the system identify the features on the screen, and reinforcement learning rewarded it for a high score. The computer achieved a high proficiency level with several games; in some cases, it performed better than expert human players. That said, it also completely bombed on other games that are just as easy for humans to master. Even more impressively in 2017, DeepMind used similar techniques to create a computer program that mastered the game Go—and could beat the world's best players. What is more, the program did this simply by playing the game against itself millions of times, with no information about how humans play.

**APPLYING AI TO LEARN FROM LARGE DATA SETS—MILLIONS OF INSTAGRAM IMAGES OR E-MAIL MESSAGES—ALLOWS SOLUTIONS TO PROBLEMS THAT ONCE SEEMED DAUNTING.**

The ability to apply AI to learn from large data sets—millions of Instagram images, e-mail messages or voice recordings—allows solutions to problems that once seemed daunting, such as image and speech recognition. Even so, it is worth remembering that my grandson has no trouble at all recognizing an animal or responding to a spoken query even with much more limited data and training. Problems that are easy for a human five-year-old are still extremely perplexing to computers and much harder than learning to play chess.

Computers that learn to recognize a whiskered, furry face often need millions of examples to categorize objects that we can classify with just a few. After extensive training, the computer might be able to identify an image of a cat that it has never seen before. But it does so in ways that are quite different from human generalizations. Because the computer software reasons differently, slipups occur. Some cat images will not be labeled as cats. And the computer may incorrectly say an image is a cat, although it is actually just a random blur, one that would never fool a human observer.

## ALL THE WAY DOWN

THE OTHER APPROACH to machine learning that has transformed AI in recent years works in the opposite direction, from the top down. It assumes that we can get abstract knowledge from concrete data because we already know a lot and especially because the brain is already capable of understanding basic abstract concepts. Like scientists, we can use those concepts to formulate hypotheses about the world and make predictions about what data (events) should look like if those hypotheses are right—the reverse of trying to extract patterns from the raw data themselves, as in bottom-up AI.

This idea can best be illustrated by revisiting the spam plague through considering a real case in which I was involved. I received an e-mail from the editor of a journal with a strange name, referring specifically to one of my papers and proposing that I write an article for the publication. No Nigeria, no Viagra, no million dollars—the e-mail had none of the common indications of a spam message. But by using what I already knew and thinking in an abstract way about the process that produces spam, I could figure out that this e-mail was suspicious.

To start, I knew that spammers try to extract money from people by appealing to human greed—and academics can be as greedy to publish as ordinary folks are for $1-million prizes or better sexual performance. I also knew that legitimate "open access" journals have started covering their costs by charging authors instead of subscribers. Also, my work has nothing to do with the journal title. Putting all that together, I produced a plausible hypothesis that the e-mail was trying to sucker academics into paying to "publish" an article in a fake journal. I could draw this conclusion from just one example, and I could go on to test my hypothesis further by checking the editor's bona fides through a search-engine query.

A computer scientist would call my reasoning process a "generative model," one that is able to represent abstract concepts, such as greed and deception. This same model can also describe the process that is used to come up with a hypothesis—the reasoning that led to the conclusion that the message might be an e-mail scam. The model lets me explain how this form of spam works, but it also lets me imagine other kinds of spam or even a type that differs from any I have seen or heard about before. When I receive the e-mail from the journal, the model lets me work backward—tracing step by step why it must be spam.

Generative models were essential in the first wave of AI and cognitive science in the 1950s and 1960s. But they also had limitations. First, most patterns of evidence might, in principle, be explained by many different hypotheses. In my case, it could be that the e-mail really was legitimate, even though it seemed unlikely. Thus, generative models have to incorporate ideas about probability, one of the most important recent developments for



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these methods. Second, it is often unclear where the basic concepts that make up generative models come from. Thinkers such as Descartes and Noam Chomsky suggested that you are born with them firmly in place, but do you really come into this world knowing how greed and deception lead to cons?

Bayesian models—a prime example of a recent top-down method—attempt to deal with both issues. Named after 18th-century statistician and philosopher Thomas Bayes, they combine generative models with probability theory using a technique called Bayesian inference. A probabilistic generative model can tell you how likely it is that you will see a specific pattern of data if a particular hypothesis is true. If the e-mail is a scam, it probably appeals to the greed of the reader. But of course, a message could appeal to greed without being spam. A Bayesian model combines the knowledge you already have about potential hypotheses with the data you see to let you calculate, quite precisely, just how likely it is that an e-mail is legitimate or spam.

This top-down method fits better than its bottom-up counterpart with what we know about how children learn. That is why, for more than 15 years, my colleagues and I have used Bayesian models in our work on child development. Our lab and others have used these techniques to understand how children learn about cause-and-effect relationships, predicting how and when youngsters will develop new beliefs about the world and when they will change the beliefs they already have.

Bayesian methods are also an excellent way to teach machines to learn like people. In 2015 Joshua B. Tenenbaum of the Massachusetts Institute of Technology, with whom I sometimes collaborate, Brenden M. Lake of New York University and their colleagues published a study in *Science*. They designed an AI system that could recognize unfamiliar handwritten characters, a job that is simple for people but extremely taxing for computers.

Think of your own recognition skills. Even if you have never seen a character in a Japanese scroll, you can probably tell if it is the same or different from one on another scroll. You can probably draw it and even design a fake Japanese character—and understand as well that it looks quite different from a Korean or Russian character. That is just what Tenenbaum's team members got their software to do.

With a bottom-up method, the computer would be presented with thousands of examples and would use the patterns found in those examples to identify new characters. Instead the Bayesian program gave the machine a general model of how to draw a character: for example, a stroke can go right or left. And after the software finishes one character, it goes on to the next.

When the program saw a given character, it could infer the sequence of strokes that were needed to draw it, and it went on to produce a similar set of strokes on its own. It did so the same way that I inferred the series of steps that led to my dubious spam e-mail from the journal. Instead of weighing whether a marketing scam was likely to lead to that e-mail, Tenenbaum's model guessed whether a particular stroke sequence was likely to produce the desired character. This top-down program worked much better than deep learning applied to exactly the same data, and it closely mirrored the performance of human beings.

## A PERFECT MARRIAGE

THESE TWO LEADING APPROACHES to machine learning—bottom up and top down—have complementary strengths and weaknesses. With a bottom-up method, the computer does not need to understand anything about cats to begin with, but it does need a great deal of data.

The Bayesian system can learn from just a few examples, and it can generalize more widely. This top-down approach, though, requires a lot of work up front to articulate the right set of hypotheses. And designers of both types of systems can run into similar hurdles. The two approaches work only on relatively narrow and well-defined problems, such as recognizing written characters or cats or playing Atari games.

Children do not labor under the same constraints. Developmental psychologists have found that young children somehow combine the best qualities of each approach—and then take them much further. Augie can learn from just one or two examples, the way a top-down system does. But he also somehow extracts new concepts from the data themselves, like a bottom-up system. These concepts were not there to begin with.

Augie can actually do much more. He immediately recognizes cats and tells letters apart, but he can also make creative and surprising new inferences that go far beyond his experience or background knowledge. He recently explained that if an adult wants to become a child again he or she should try not eating any healthy vegetables, because they make a child grow into an adult. We have almost no idea how this kind of creative reasoning emerges. In fact, in a 2017 paper in the *Proceedings of the National Academy of Sciences USA,* our lab found that children were indeed better at this kind of creative thinking than adults. And in 2018 DARPA, the Department of Defense's advanced research arm, put out a call for projects that could simulate child development in computers.

We should recall the still mysterious powers of the human mind when we hear claims that AI is an existential threat. Artificial intelligence and machine learning sound scary. And in some ways, they are. The military is researching ways to use these systems to control weapons. Natural stupidity can wreak far more havoc than artificial intelligence, and we humans will need to be much smarter than we have been in the past to properly regulate the new technologies. Moore's law is an influential force: even if advances in computing result from quantitative increases in data and computer power, rather than conceptual revolutions in our understanding of the mind, they can still have momentous, practical consequences. That said, we shouldn't think that a new technological golem is about to be unleashed on the world. SA

**Alison Gopnik** is a professor of psychology and an affiliate professor of philosophy at the University of California, Berkeley. Her research focuses on how young children learn about the world around them.

### MORE TO EXPLORE

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# The Brilliance Trap

## How a misplaced emphasis on genius subtly discourages women and African-Americans from certain academic fields

*By Andrei Cimpian and Sarah-Jane Leslie*

IN THE 1980S PHILOSOPHERS WOULD SOMETIMES SPEAK OF "THE BEAM"—A METAPHORICAL spotlight of intellectual brilliance that could illuminate even the most complex philosophical conundrums. Only some lucky philosophers were ever born with the Beam, and their work represented the gold standard of the field. Anyone who lacked the Beam was forever condemned to trail behind them intellectually. One of us (Leslie) would share this sort of story whenever we would see each other at conferences. The two of us were trained in different disciplines (Leslie in philosophy and Cimpian in psychology), but we studied similar topics, so we would get together regularly to catch up on research and talk about our experiences as members of our respective fields. Psychology and philosophy are quite similar in their substance (in fact, psychology was a branch of

*Illustrations by Allison Seiffer*



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philosophy until the mid-1800s), but the stories we told painted a picture of two fields with vastly different views on what is important for success. Much more so than psychologists, philosophers value a certain *kind of person*—the brilliant superstar with an exceptional mind. Psychologists, in contrast, are relatively more likely to believe that the leading lights in their field grew to achieve their positions through hard work and experience.

At first, we viewed philosophy's obsession with brilliance as a quirk—a little strange but innocuous. Other things seemed like bigger problems in Leslie's field, such as its inability to attract women and minorities. Despite sustained attention to issues of underrepresentation in recent years and some efforts to alleviate them, women still accounted for fewer than 30 percent of the doctoral degrees granted in philosophy in 2015; African-Americans made up only 1 percent of philosophy Ph.D.s. The field of psychology, on the other hand, has been quite successful in attracting and retaining women (72 percent of newly minted Ph.D.s), and African-Americans held 6 percent of its 2015 doctoral degrees, which admittedly still falls short of their share of the general population but is nonetheless six times the ratio in philosophy.

We could not wrap our minds around the discrepancy. Our fields have so much in common—both philosophers and psychologists ask questions about how people perceive and understand the world, how they decide between right and wrong, how they learn and use language, and so on. Even the few salient differences—such as psychologists' greater use of statistics and randomized experiments—are becoming blurred nowadays with the huge increase in the popularity of experimental philosophy, in which philosophers conduct surveys and experiments to explore different perspectives on morality, for example. How could two such closely related fields be so vastly different in membership?

## A BRILLIANT IDEA

THE CLOSEST THING either of us has ever had to a eureka moment came several years ago when we connected two threads running through the anecdotes we had been sharing. We were having dinner with a group of philosophers and psychologists at a conference, and the conversation happened to turn, in quick succession, from philosophers' infatuation with brilliance to the gender gap in their field. This chance juxtaposition brought to mind for us a connection we had never considered before: maybe the premium philosophers place on brilliance is actually the reason why so few of their colleagues are women or minorities. We did not discount the benefits of brilliance. Rather we wondered whether genius was more easily overlooked in women and African-Americans. Could it be that insistence on the need for a keen intellect in a particular field was tantamount to hanging a "Keep Out" sign to discourage any newcomers who did not resemble that field's current members?

On the surface, an emphasis on brilliance does not favor one group over another; as far as scientists can tell, cognitive ability is not intrinsically tied to gender or race. Philosophers seek a certain quality of mind—regardless of whose mind it is. This seemingly logical preference quickly becomes problematic, however, in light of certain shared societal notions that incorrectly associate superior intellect with some groups—for example, white males—more than others.

Even among the academics present that night, one of the views expressed was that men and women just thought differently. Women were alleged to be more practical and anchored in reality, whereas men were more willing to engage in the kind of counterfactual, abstract reasoning that is viewed as a sign of philosophical brilliance. We started to wonder whether such stereotypes, which amount to equating brilliance with men, might well dissuade women from entering a field that holds this quality in high esteem. Moreover, current members of such a field might themselves hold different expectations about the prospects of men and women and might evaluate and encourage them differently as a result. The same logic extends to race: our country has a long history of portraying African-Americans as intellectually inferior, which is particularly likely to affect their participation in a field that focuses so single-mindedly on the quality of one's intellect. Considering these stereotyped attitudes, which are unsupported by science, philosophy's fascination with brilliance may have a real impact on its diversity.

Later that night the two of us talked about our insight. We speculated whether its implications extend beyond our home disciplines. Talk of brilliance is common in academia and—it seemed to us—quite common in fields that have similar issues with diversity, such as science, technology, engineering or mathematics. Might our anecdotal comparison of philosophy and psychology have something new to say about the underrepresentation of women and minorities in these disciplines?

The more we thought about it, the more we realized that our brilliance hypothesis might also explain some of the variability in gender and race gaps *among* different scientific fields. For example, women make up nearly 50 percent of doctoral degrees in biochemistry but just more than 30 percent of Ph.D.s in organic chemistry. The difference cannot easily be explained by the content of the fields, in which there is considerable overlap, or by their history—biochemistry emerged from organic chemistry at about the same time psychology separated out of philosophy as an independent discipline. We wondered whether the demographic differences between such sibling subjects, as well as more generally among scientific fields, could be explained in part by the extent to which they emphasize exceptional intellectual talent as the key to success.

### IN BRIEF

**Academic fields that prize** the brilliance of their members, the authors found, are likely to be less diverse in gender and racial makeup.

**Although innate cognitive ability** is not, as far as scientists can tell, tied to gender or race, it is psychologically easier to ascribe this trait to people from groups stereotypically assumed to be intelligent.

**Women and African-Americans** may subconsciously interpret a field's emphasis on brilliance as a subtle "Keep Out" sign that dissuades them from entering certain disciplines in the sciences and humanities.



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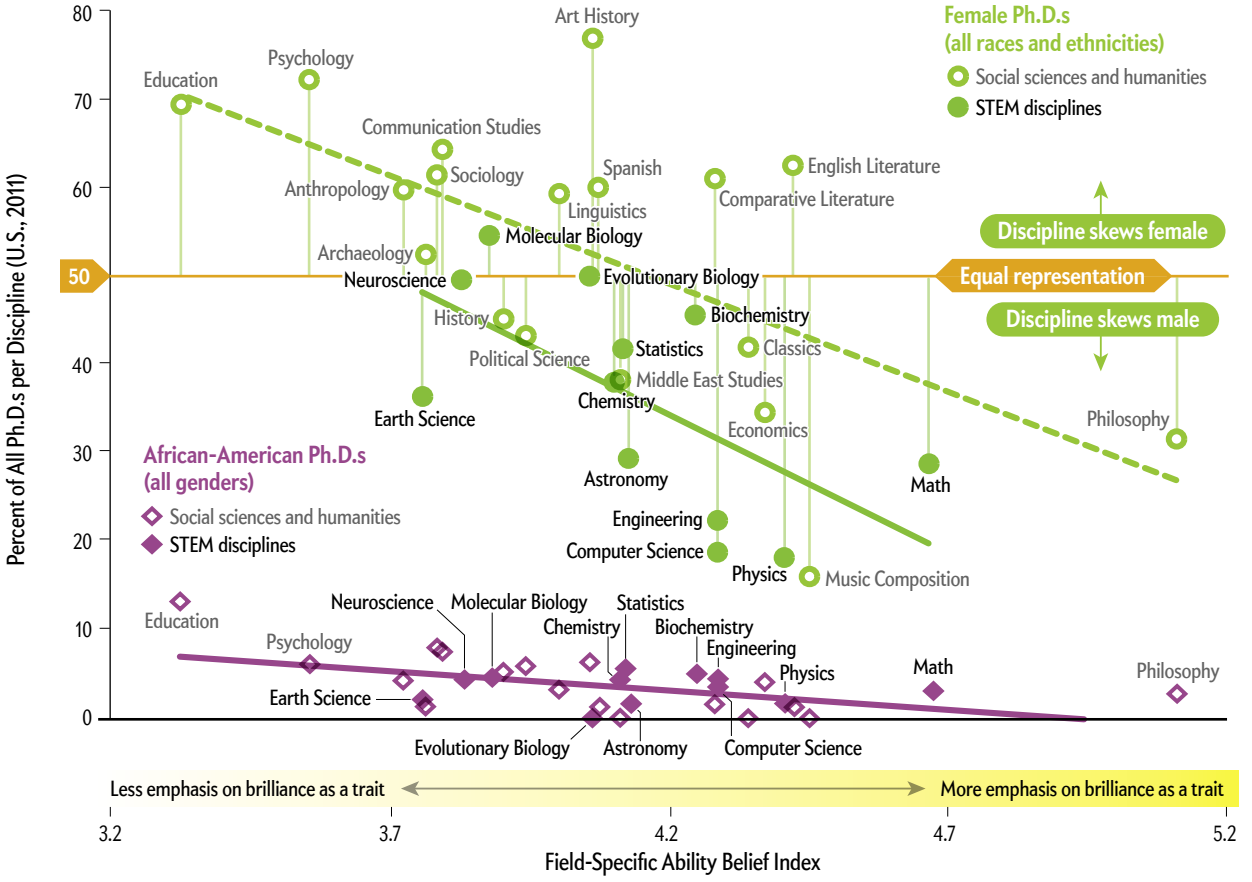
# How Stereotypes about Genius Affect Women and Minorities in Academia

A survey of almost 2,000 professionals in 30 academic fields determined how strongly they believed that the trait of brilliance, as measured by a so-called field-specific ability belief index, mattered for success in their discipline. Fields with higher scores, such as physics, math and philosophy, awarded fewer advanced degrees to women and African-Americans, compared with neuroscience and psychology, which scored lower. The results suggest that many fields implicitly equate brilliance with white males.




SOURCE: "EXPECTATIONS OF BRILLIANCE UNDERLIE GENDER DISTRIBUTIONS ACROSS ACADEMIC DISCIPLINES," BY SARAH-JANE LESLIE ET AL., IN *SCIENCE*, VOL. 347; JANUARY 16, 2015

## SUCCESSFUL MINDSETS

OUR EARLY CONJECTURES quickly reminded us of the rich body of work developed by psychologist Carol Dweck of Stanford University. Dweck and her colleagues have shown that one's beliefs about ability matter greatly for one's ultimate success. A person who sees talent as a stable trait (a "fixed mindset" in Dweck's terminology) is motivated to show off this aptitude and avoid mistakes, which presumably reflect the limits of that gift. In contrast, a person who adopts a "growth mindset" sees his or her current capacity as a work in progress. In other words, ability is a malleable quantity that can usually be increased with more effort and better strategies. For a person with a growth mindset, mistakes are not an indictment but rather a valuable signal highlighting which of their skills are in need of work.

Although Dweck initially studied mindsets in individuals, she and Mary Murphy, now at Indiana University Bloomington, recently suggested that organized groups of people, such as companies and clubs, may also hold these sorts of views. We took that idea a step further and considered whether they might permeate entire disciplines as well. The fascination with brilliance in philosophy and other areas could conceivably create an atmosphere in which displays of intellectual prowess are rewarded, and imperfections are to be avoided at all costs. In combination with the stereotypes suggesting that genius is unevenly distributed across groups, such a field-wide perspective could easily turn toxic for members of stereotyped groups, such as women or African-Americans. After all, it is easy to "see" imperfections and inadequacies in those people whom you expect to have them.

Several long phone conversations later, we had a tentative plan for putting our ideas to the test. We would contact aca-

*Graphic by Jen Christiansen*



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demic professionals from across a wide range of disciplines and ask them whether they thought that some form of exceptional intellectual talent was necessary for success in their field. We would then look up statistics on the gender and racial/ethnic composition of the people obtaining Ph.D.s in these disciplines, which the National Science Foundation freely supplies on its Web site. If our hunch was correct, we should see that those disciplines that place more value on brilliance would tend to have fewer female and African-American Ph.D.s. This pattern should hold not just at the macro level—when comparing the hard sciences, for example, with the social sciences and the humanities—but also *within* these broad domains—for disciplines as similar as philosophy and psychology.

More than a year and thousands of e-mailed surveys later, we and our collaborators Meredith Meyer of Otterbein University in Ohio and Edward Freeland of Princeton University finally had an answer to some of our questions. Equal parts relieved and exhilarated, we saw that the answers received from almost 2,000 academics across 30 fields matched the distribution of Ph.D.s in the way we had expected. Fields that placed more value on brilliance also conferred fewer Ph.D.s on women and African-Americans. The greater the emphasis on this single fixed trait, the fewer doctoral degrees were awarded to either of these groups. The proportion of female and African-American Ph.D.s in psychology, for example, was higher than the parallel proportions for philosophy, math or physics.

Next, we separated the responses in the physical and biological sciences from those in the humanities and social sciences. Analyses of these subgroups indicated that a stronger emphasis on brilliance correlated with fewer female and African-American Ph.D.s regardless of whether we compared physics with biology or philosophy with sociology. It seemed that we had stumbled onto an explanation that was general enough to describe the representation of multiple stereotyped groups in fields across the entire academic spectrum.

## ALTERNATIVE IDEAS

OUR EXCITEMENT ABOUT THESE DATA ASIDE, all we had really shown at this point was a correlation between the presumed desirability of a fixed trait—brilliance—with a dearth of women or African-Americans in a given field. We had not yet demonstrated cause and effect. Certainly many other plausible explanations for the gender imbalances have been proffered over the years—from a heavier workload that favored single men and those with wives who did not work outside the home to a supposed female preference for working with living organisms, as opposed to inanimate objects. We needed to determine whether we were bringing something new to the table—perhaps our explanation reduced to one that had been previously offered.

We carefully examined the most common alternatives. For instance, did our brilliance measure simply track differences between fields in their reliance on math? We looked at the math portion of incoming students' Graduate Record Examinations (GREs) as a proxy. Beliefs about brilliance still predicted women's representation above and beyond those scores. Similarly, we found no support for the common view that women are underrepresented in "high-powered fields" because they prefer a better work-family balance. We asked the academics in our sample how many hours they worked per week—both on- and off-campus. Taking into account these differences in workload did not, however, reduce the explanatory power of beliefs about brilliance; this single variable still predicted the magnitude of gender gaps across the 30 disciplines. We also considered the prevalent thought that women might be more interested in working with (and have a better intuitive understanding of) people, whereas men prefer inanimate systems. But an analysis of the many branches of philosophy, for example, that do in fact consider people—and are still dominated by men—basically blew that idea out of contention.

As often happens in research, this initial study made it clear to us how much we did *not* yet know about the phenomenon that we were investigating. For example, we realized it would be important to know if academics' beliefs about brilliance predict gender and race gaps at earlier points in students' educational trajectories. We were very interested in testing our idea



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at the bachelor's level, which is the gateway to students' later careers. Do field-level messages about the importance of brilliance relate to the majors that young women and African-Americans ultimately pursue?

The answer to this question is yes, as we reported in *PLOS ONE* in 2016 when we analyzed anonymous student evaluations of their college instructors on RateMyProfessors.com. We found that undergraduates were nearly twice as likely to describe male professors as "brilliant" or a "genius" compared with female professors. In contrast, they used such terms as "excellent" or "amazing" equally often for men and women on the popular Web site. We determined that the overall amount of talk about brilliance and genius in the student reviews (which is a proxy for a field's emphasis on these qualities) correlated closely with a lack of diversity in completed majors.

## ORIGINS OF STEREOTYPES

FURTHER INVESTIGATION showed that nonacademics share similar notions of which fields require brilliance. Exposure to these ideas at home or school could discourage young members of stereotyped groups from pursuing certain careers (such as those in science or engineering) before they even set foot on a college campus.

At this point, we realized we needed to investigate the acquisition of these stereotypes. When do young people in our culture start thinking that some groups have more brilliant people in them? On the one hand, it could be that this stereotype emerges late in development, after sustained exposure to relevant cultural input (for example, media portrayals of brilliance and gender-biased expectations from parents, teachers, professors and peers). On the other hand, evidence from developmental psychology suggests that children are cultural sponges—incredibly sensitive to signals in their social environments. In fact, youngsters in the early elementary grades seem to have already absorbed the stereotypes that associate math with boys and reading with girls. From this perspective, we might expect that stereotypes about brilliance would also be acquired early in life.

To explore this idea, we asked hundreds of five-, six- and seven-year-old boys and girls many questions that measured whether they associated being "really, really smart" (our child-friendly translation of "brilliant") with their gender. The results, which we published in 2018 in *Science,* were consistent with the literature on the early acquisition of gender stereotypes yet were still shocking to us. Male and female five-year-olds showed no difference in their self-assessment. But by age six, girls were less likely than boys to think that members of their gender are "really, really smart."

Finding these stereotypes so early in childhood made us ask whether they might already begin to constrain boys' and girls' interests. We introduced another group of five-, six- and seven-year-olds to unfamiliar gamelike activities that we described as being "for children who are really, really smart." We then compared boys' and girls' interest in these activities at each age. The results revealed no gender differences at age five but significantly greater interest from boys at six and seven years of age—which is exactly where we saw the stereotypes emerge. In addition, the children's own stereotypes directly predicted their interest in these novel activities. The more a child associated brilliance with the opposite gender, the less interested he or she was in playing our games for "really, really smart children." This evidence suggests an early link between stereotypes about brilliance and children's aspirations. Over the rest of childhood development, this link may funnel many capable girls away from disciplines that our society perceives as being primarily for brilliant people.

The hard work of figuring out how best to put all this information to use—how to intervene—lies ahead of us. But a few suggestions follow pretty directly from the evidence we have so far. Minimizing talk of genius or brilliance with students and protégés may be a relatively easy and effective way of making one's field more welcoming for members of groups that are negatively stereotyped in this respect. Given current societal stereotypes, messages that portray this trait as singularly necessary may needlessly discourage talented members of stereotyped groups. The changes may need to go a little deeper than talk, however, and tackle some of the entrenched, systemic issues that accompany a field's fascination with brilliance. Refraining from mentioning the Beam will not help young women in philosophy if the rest of the field's practices continue to be implicitly anchored in the idea that brilliance is all that matters.

Another key takeaway is that we may need to intervene earlier than conventional wisdom suggests. Our developmental data indicate that some of the psychological processes that work against diversity in fields that value brilliance can be traced all the way back to elementary school. Waiting until college to step in and ensure that all young people have a fair shot at finding the careers that might suit them no longer seems like the best-timed intervention—we as a society would be wise to encourage a growth perspective, as opposed to a fixed-trait mindset, in young children as well. SA

### FRIENDLY FIELDS

Of the 17,505 doctorates awarded in science and engineering to women in the U.S. in 2015,

**40%**

were given in the life sciences.

Of the 1,307 of such doctorates granted to African-Americans, more than

**40%**

were in psychology and the social sciences.

SOURCE: *DOCTORATE RECIPIENTS FROM U.S. UNIVERSITIES: 2015.* NATIONAL CENTER FOR SCIENCE AND ENGINEERING STATISTICS. NATIONAL SCIENCE FOUNDATION, 2017

**Andrei Cimpian** is an associate professor of psychology at New York University.

**Sarah-Jane Leslie** is Class of 1943 Professor of Philosophy at Princeton University.

### MORE TO EXPLORE

**On Being an "African American Scientist."** Raynard S. Kington in *Scientist,* Vol. 27, No. 5; May 2013. www.the-scientist.com/?articles.view/articleNo/35251/title/On-Being-an-African-American-Scientist-

**Expectations of Brilliance Underlie Gender Distributions across Academic Disciplines.** Sarah-Jane Leslie et al. in *Science,* Vol. 347, pages. 262–265; January 16, 2015.

**The Frequency of "Brilliant" and "Genius" in Teaching Evaluations Predicts the Representation of Women and African Americans across Fields.** Daniel Storage et al. in *PLOS ONE,* Vol. 11, No. 3, Article No. e0150194; March 3, 2016.

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# Head Games

## Match wits with the Mensa puzzlers

### 1 CANDLE COUNT

Casey and his mom are both celebrating birthdays and turning ages that are perfect squares. In four years, Casey's age will be exactly half his mother's age. How old are they now?

### 2 WHAT'S NEXT?

What number is missing from this sequence?

**1 3 4 3 9 5 16 4 25 _ 36 3**

### 3 WORD WATCH

What do the following words have in common?

**AWNING**

**EAST**

**EARNED**

### 4 RESCUE LOG

Firefighters Dean and Henry rescued a number of cats from trees in one week. Henry rescued twice as many cats as Dean. The total number of cats rescued is a perfect square. Neither rescued more than one cat a day. How many cats did each man rescue?

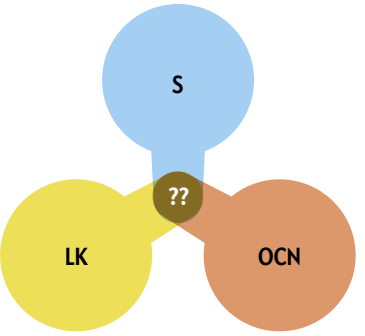
### 5 SOUNDS OF SCIENCE

The following is a clue for what science-related word?

**4N6**

### 6 FINDING VOWELS

The same two vowels have been plucked from these three related words. Can you put the words back together?




### 7 SCHEDULING PROBLEM

If JT works one shift every second day, Laura works once every third day, and Aditya works every fifth day, how often do all three colleagues work together?

### 8 TAKING SHAPES

Using the first three shapes and values as a guide, find the value that corresponds to the last shape.

**22** **40**

**01** **??**

### 9 GREEN FIGURES

A recycling dumpster holds a maximum of 27 bags of recycled materials. An apartment building puts out about nine bags of recycling every month. Two dumpsters could service how many apartment buildings in one month?

### 10 MISSING DIGITS

What number should replace the question mark below?

**24 … 8.5**

**35 … 15.6**

**18 … 8.125**

**68 … ?**

## ANSWERS

1. 16 and 36.
2. 4. The sequence shows each perfect square up to 36, followed by the number of letters in the word for its square root—in this case, "five."
3. Each word can become a new word by adding "Y": yawning, yeast and yearned.
4. Henry rescued six cats, and Dean rescued three.
5. Forensics (four N six).
6. A and E: SEA, OCEAN and LAKE.
7. Every 30th day ($2 \times 3 \times 5$).
8. 21. Each number displays the number of straight lines, followed by the number of curves. The last shape has two straight lines and one curved line.
9. Six.
10. 48.75. The answers are made by multiplying the digits (48), then dividing them (0.75) and writing those answers together.

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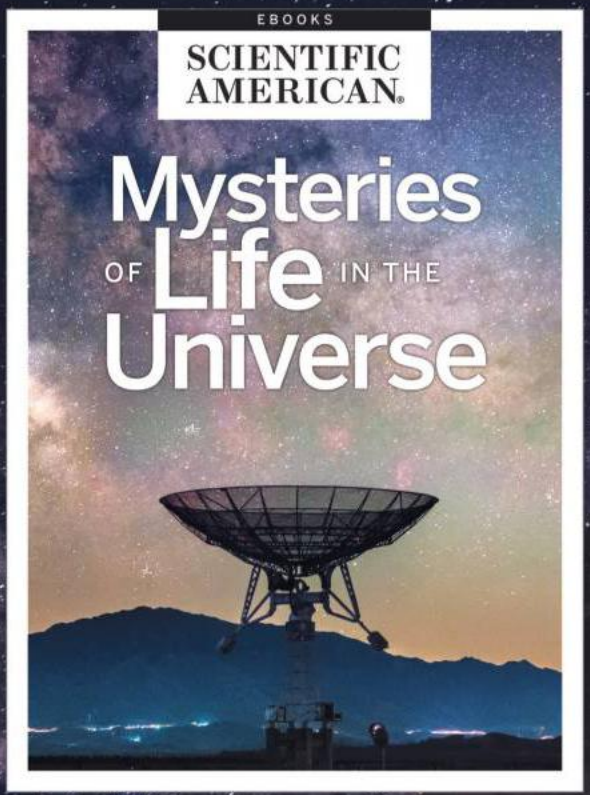


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